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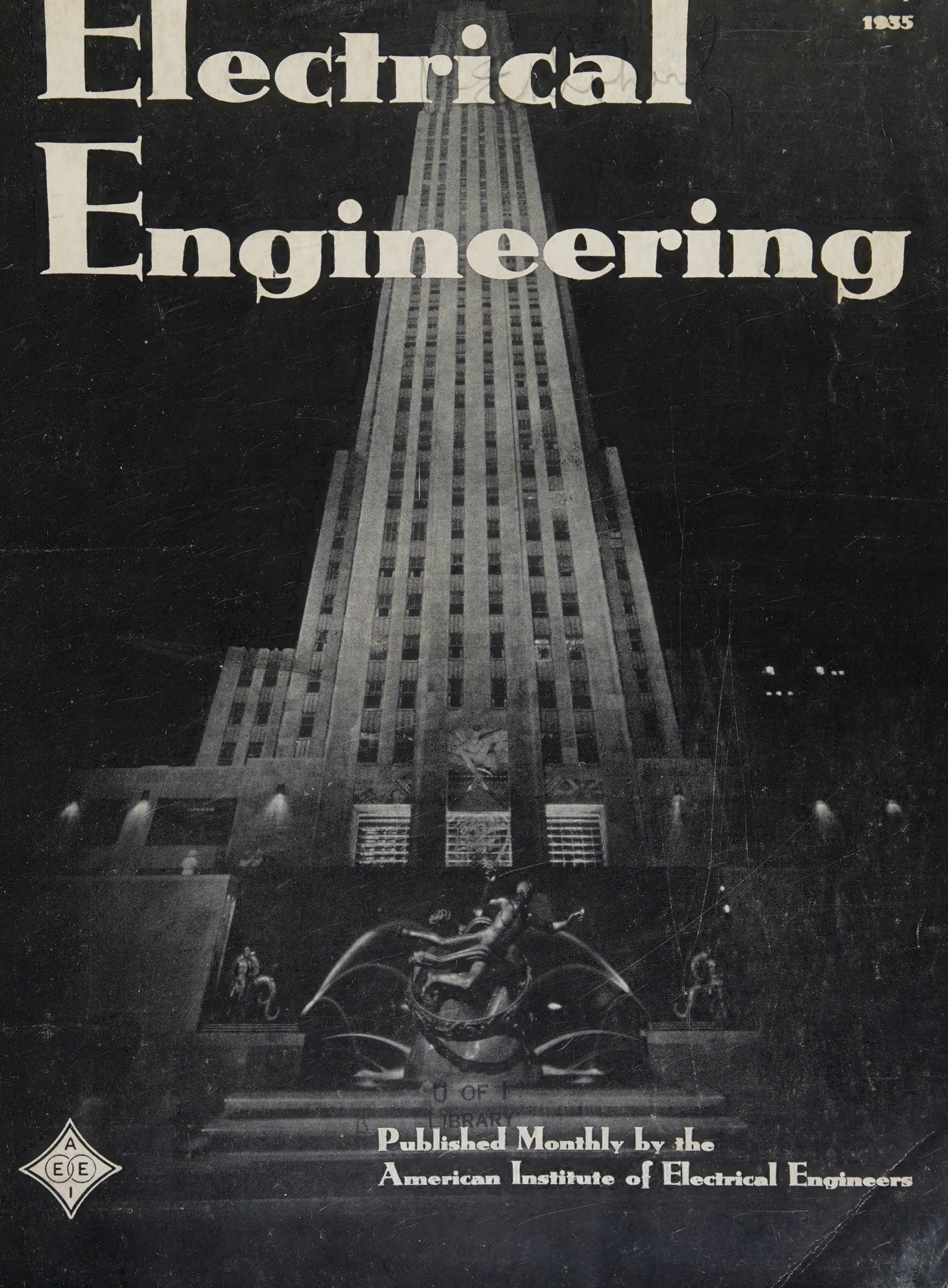

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This Month—

Front Cover

Night view of the 70 story RCA Building, Rockefeller Center, New York City. This will be one of the centers of interest during the forthcoming 1935 A.I.E.E. winter convention to be held January 22–25

Photo by Wendell Mc Rae

Educational Series—No. 13

A.I.E.E. Papers

—Turn to next page

X Rays—What Should We Know About Them?

By GEORGE L. CLARK, Fellow Am. Phys. Soc.
University of Illinois, Urbana

Most engineers are familiar with some of the more common uses of X rays, and many have had occasion to apply them in their daily work; to many, however, the picture of this versatile tool and its numerous applications is quite incomplete. The latter will find this article particularly interesting and instructive. The nature of these rays, the mechanism of their production, and the fundamental principles underlying their many applications in medicine, physics, chemistry, biology, and industry are outlined briefly. Perhaps the most striking application is the determination of the ultimate fine structure of materials from the results of diffraction analysis, in which the X rays provide a supermicroscopic vision of matter. This is the thirteenth and concluding article of the "Science Series for Engineers" developed under auspices of the A.I.E.E. committee on education.

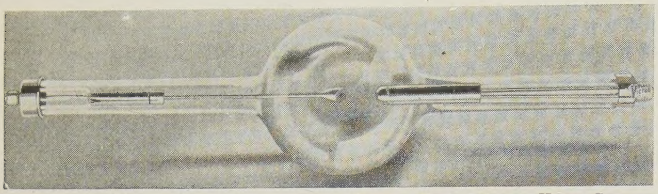
EVERY LAYMAN has come to the realization that the X ray department is an essential part of the equipment of every modern hospital or clinic. He also knows that the medical applications of these rays, discovered just 39 years ago, are classified as diagnosis and as therapy. He probably has seen the bones of his own hand held between the X ray tube and a fluoroscopic screen. He may have been a patient for whom broken bones were set, internal tumors discovered, foreign bodies exactly located and extracted without guess work, tuberculosis indicated or disproved, or a host of other ailments diagnosed from X ray films. He should be familiar with the fact that cancer and other pathological conditions are treated successfully by X rays or gamma rays from radium.

Again the layman may have heard that biologists have been producing all sorts of peculiar changes in fruit flies by X raying eggs; that physicists have been utilizing these same rays to explore the architecture of atoms; that chemists have been unfolding the building plan of crystals in some marvelous way with these rays; that all the welds in Boulder Dam construction are being subjected to some kind of an X ray test in the interest of soundness and permanence; that some of the greatest industries have X ray research laboratories in no way concerned with medical problems; but unless the layman has had special training, the nature of these rays, the mechanism of their production and measurement, and the fundamental principles of this versatile agency in medicine, physics, chemistry, biology, and industry may remain a mystery, and the full power and possibilities of the scientific tool unrealized.

So one may ask, first of all: What are these rays, designated originally by the letter "X" because of their mysterious nature, and sometimes by the name of the great German physicist who accidentally discovered them in 1895—Röntgen rays? They are invisible and have no electrical or magnetic properties whatever; and yet when they impinge upon certain chemicals and minerals these substances glow with a visible light. They blacken a photographic film just as light does. In passing through air or any other gas, they "electrify" or ionize the gas so that an electric current will flow between charged plates through the gas. Crystals such as rock salt reflect X rays at certain definite angles. Measurement also shows that under very special conditions they may be reflected from mirrors, refracted or bent very slightly in passing from air into a solid, diffracted by passing across lines ruled very closely together on glass, and polarized. Some of these latter properties immediately suggest light, for ordinary white light certainly can be reflected from mirrors, spread out into a spectrum or rainbow of colors by a prism or ruled grating, bent in passing from air into water or glass, and polarized. However, there are some marked differences apparently between light and X rays. The latter have the power of penetrating matter that is entirely opaque to ordinary light. This can be proved by placing the hand between the X ray tube and a photographic film or a fluorescent screen made of some chemical substances, such as zinc silicate, calcium tungstate, or barium platinocyanide, which glow under the action of X rays. The bones of the hand can be seen clearly outlined in finest detail. These rays have passed through the hand, but much more easily through soft tissue than through dense bones. In other words, a far greater absorption of the rays takes place in the bones than in the flesh, with the result that in the path of the bones less blackening of the film or brightening of the screen occurs than for adjacent areas, and a shadowgraph is produced. By virtue of this highly penetrative quality of X rays, the interior of the body or of any object can be examined easily without in any way cutting open or damaging the body or the object.

So one may conclude that X rays are like ordinary light in many respects, but differ at least in the property of penetration. Strangely enough, as these comparison are extended, it is found that at least a part of the cosmic rays permeating all space (which have been mentioned frequently in newspapers), the gamma rays from radium, X rays, ultra-violet light, visible light, infra-red or heat rays, and even radio waves, all have fundamental similarities. They

differ only in wave length. Light is to be considered as some kind of wave motion of electromagnetic origin since many of its properties can be explained only upon such a basis. Now yellow light can be shown to have a wave length a little less than 6,000 Ångström units, that is, 0.00006 centimeter (one Ångström unit is equal to 10^{-8} centimeter). X rays



Courtesy General Electric X-Ray Corp.

Fig. 1 Conventional type of modern Coolidge X ray tube

are just like light except that their wave lengths are very much shorter. Medical science ordinarily is interested in X rays with wave lengths of 0.1 to 1 Ångström unit, although shorter and longer waves have been measured and can be produced by the X ray machine. X rays are penetrating because of those short wave lengths; the shorter, the thicker will be the object through which the rays may penetrate. The cosmic rays, which man thus far cannot produce, probably penetrate 18 feet of lead or more.

The possibilities of future development are illustrated by the recent achievement of 2 Germans, Lange and Brasch, in producing X rays from a tube at 3,000,000 volts with a minimum wave length of only 0.004 Ångström unit. One such tube could produce rays of an intensity corresponding to that from a million dollars worth of radium. A half dozen hospitals in the United States now treat patients with X rays generated at a million volts.

Light is produced so abundantly by natural processes—illumination by the sun particularly—that one wonders next how X rays are produced. It is known that the gamma rays, which are the same as the very shortest X rays produced at the very highest voltages, come from spontaneously decomposing radioactive minerals on the earth. Unless X rays exist in the interior of the hot stars, as Jeans and Eddington maintain, nature cannot be depended upon to produce these valuable rays. Röntgen discovered X rays because he happened to be experimenting with a glass bulb. This bulb was nearly exhausted of air by suitable pumps, and 2 metal electrodes sealed into the bulb were connected with the terminals of an induction coil so that a high difference of potential existed between them.

Development of the X ray tube to the present highly efficient unit (which certainly can be improved still further) forms a most interesting story. With all the numerous modifications and designs for different purposes, all X ray tubes operate on the same principle. The essential parts of the X ray apparatus in the hospital are as follows: The tube in which X rays are produced, a high voltage transformer which supplies potentials of 100,000 volts or more from ordinary 110 or 220 volt a-c electric circuits, and a rectifier which changes alternating current to direct current so that one end of the X ray tube is always at positive potential and the other negative (although the X ray tube itself can rectify alternating current to direct current at potentials lower than 100,000 volts). In the X ray tube or bulb such as is illustrated in figure 1, which is exhausted of air to a very high vacuum, are 2 electrodes; one is a heavy piece of metal which looks like, and is, a target; the other consists of a fine spiral of tungsten wire which is heated to incandescence by a small independent electric current. Many years ago Edison, the great inventor, discovered that a hot wire emitted electrons, the tiny corpuscular negatively charged units of electricity. These electrons will pass at high speed across space to a positively charged electrode. In the X ray tube, therefore, a target (anode or anticathode) is bombarded by these minute electrical projectiles. The sudden stopping of these rapidly moving electrons results in X rays being generated at this target; a portion of the energy of motion is converted into radiation energy. The rays then pass out through the walls of the tube and through the body or other object. The higher the voltage, the faster will the electrons move and the "harder" or more penetrating or shorter in wave length will be the X rays.

All these phenomena, including the absorption of the rays in the human body, are governed by fundamental physical laws. The proper use of X rays for diagnosis and therapy involves absolute knowledge of the *quality* (or wave length distribution) of the rays and the *quantity* or dose. The proper voltage to apply to the X ray tube can be ascertained definitely for each medical application. Much "softer" rays (and lower voltages) will suffice for examination of a broken finger than for a complete chest radiograph. Skin diseases must be treated with soft X rays (voltages even as low as 8,000 volts for the so-called "grenz" rays) since only these will be absorbed—a process that necessarily must precede therapeutic effect. Rays with short wave lengths would pass through the skin layer with little

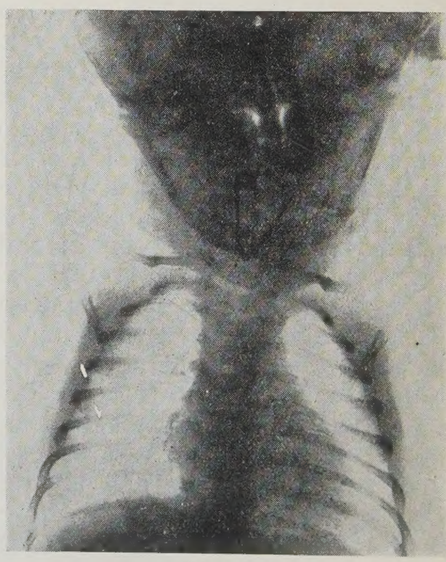


Fig. 2. Typical medical radiograph for location of foreign body (safety pin in throat of small baby)

or no effect. However, to reach a deep seated tumor the more penetrating rays must be used. If it were possible to generate X rays under given conditions with only a single wave length, the whole matter of medical X ray science would be greatly simplified; but, as a matter of fact, the beam generated in the X ray tube is quite heterogeneous and contains a wide range of wave lengths with widely varying absorbability and therapeutic effects. However, the whole heterogeneous beam will be found to have the same degree of absorption in a screen as some monochromatic ray (one with a single wave length). In other words, the complex beam has an "effective" wave length that is definite and that characterizes the beam always generated under the same conditions. The X ray technician may place a sheet of copper or aluminum in the beam to serve as a filter. These tend to make the X ray beam more nearly homogeneous by screening out the softer rays in the mixture, and thus control more perfectly the known characteristics of the beam.

Besides the quality, the quantity or dosage of X rays must be accurately controlled and measured, particularly in therapy if the best results are to be obtained, or indeed if deleterious effects of this powerful agent are to be avoided. In 1928 an international unit of dosage, the Röntgen unit or "*r*," based upon the ionizing power of the rays upon air, was adopted. Treatments for cancer, therefore, are designated in *r* units per minute.

Medical Diagnosis

Little need be said further concerning radiography or diagnosis by X rays, since this paper is not concerned with details of technic which must be gained by proper training and experience. Bones, teeth, foreign bodies (figure 2), and any dense parts are thrown immediately in shadow relief. A whole science has rapidly developed to the end of outlining some of the soft tissues and organs. Barium meal is fed to patients for the examination of the alimentary canal. Barium salts are heavily absorbing for X rays. The meal lines the canal without being absorbed by the body, and, therefore, outlines the tract. Injection of iodized oil and other chemical substances that are concentrated specifically in some organ also serve to assist in diagnosis of any normal and pathological condition. Thus gall bladder, kidneys, and other small soft organs can be distinguished clearly on films with proper technic. Diagnosis of conditions in pregnancy is being extended rapidly although greatest care is essential so that no injury occurs from radiation. In case of the possibility of twins, the X rays disclose such a contingency with certainty and thus make possible suitable preparation. X ray photographs of mummies, such as are on display at the Field Museum in Chicago, Ill., prove convincingly that these ancient people had the same kinds of ailments—rickets, tuberculosis, etc.—as afflict modern man. X ray equipment for diagnosis has been improved to such an extent that exposure of only $^{1}/_{100}$ second is required with tubes through which a current of 1,000 milliamperes may be passed.

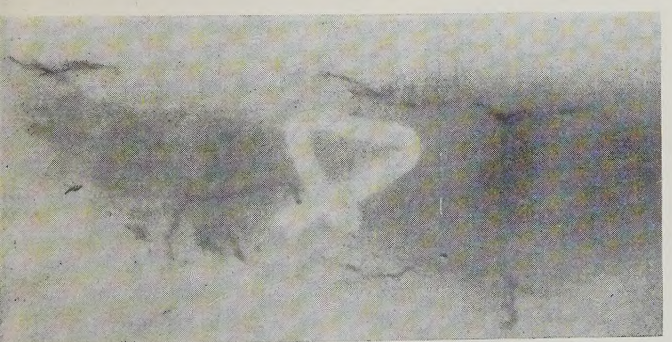


Fig. 3. Radiograph of cast steel showing internal cracks

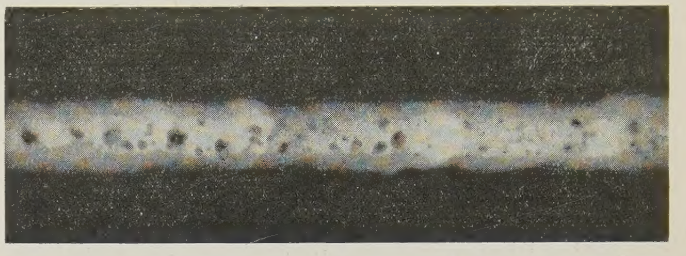


Fig. 4. Radiograph of imperfect weld

Industrial Radiography

Just as the inside of the opaque human body may be observed on the photographic film or fluorescent screen by virtue of the differential absorption of penetrating X rays, so also may any material object be radiographed without damage for the purpose of determining the gross structure and presence of inhomogeneity or defect. The immeasurable importance of this information is evident in terms of the satisfactory behavior or failure of metal or other objects of practical utility and of the safety of human life which so frequently is involved. The value of this method in promoting safety, in eliminating expensive machining operations on defective castings, for example, and in establishing proper technic to assure sound materials is so generally well known that comment scarcely is required.

Numerous industries have installed X ray plants as necessary equipment. A change in boiler code has made it practically essential that welded pressure vessels be examined radiographically in order to assure soundness. The technic of industrial radiography is practically the same as that employed in medical diagnosis. It has seemed to be entirely empirical in that suitable results were a matter of trial and failure. Just now, however, the technic is becoming so thoroughly scientifically based that radiography may be termed an exact science. Standardized data have been plotted in charts from which the exact time of exposure for a given thickness of iron may be ascertained. Such graphs, of course, apply only for a fixed set of conditions such as distance from specimen to photographic film,

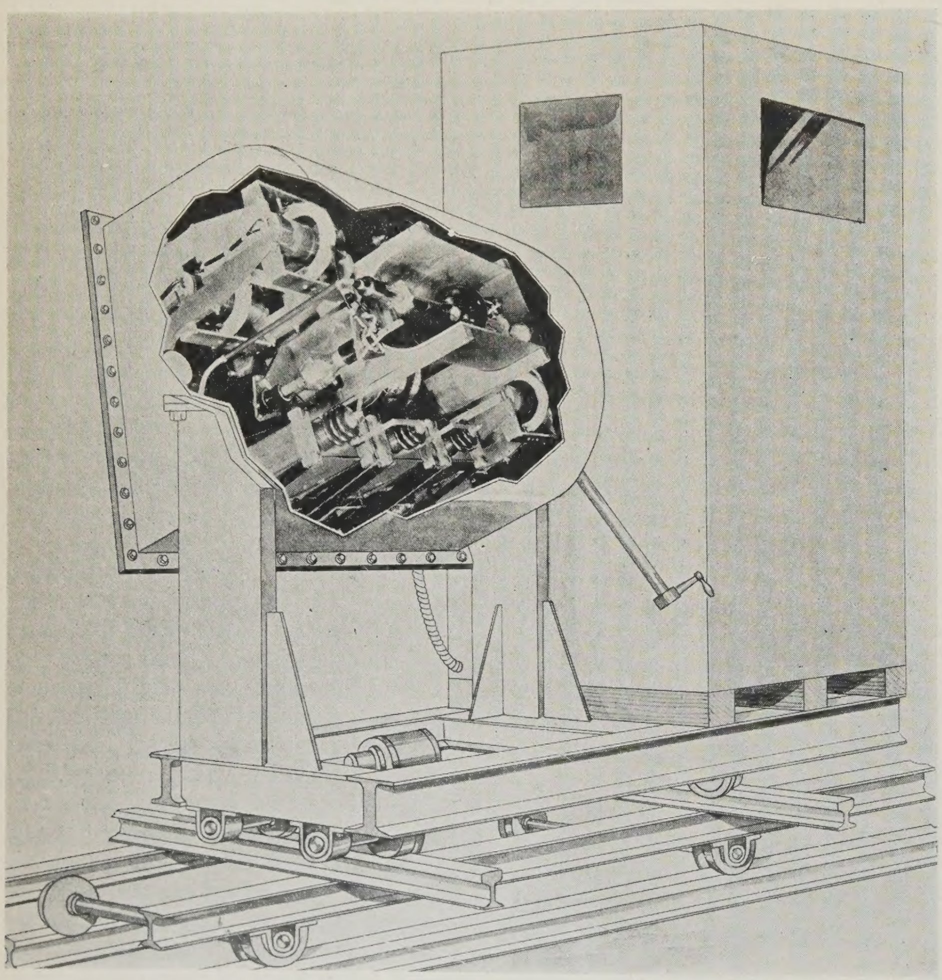
kind of film, use of intensifying screens, etc. Standard graphs have been published also for aluminum, copper, brass, and other materials. Next to quantitative aspects, the problem of greatest interest in radiography has been in the possibilities of examining still thicker sections by the use of special new X ray tubes operating at higher voltages than heretofore available. The practicable limit for iron or steel with commercial deep therapy tubes operating at voltages less than 300 kv has been about $4^1/_2$ inches. Recent experiments have been conducted with special new tubes operating at voltages up to 440 kv; however, increasing voltages give increasingly smaller increments in the limits of penetration, so that above 300 kv the increase in material thickness becomes almost inappreciable. Thus very short wave lengths, scattering, and recoil coefficients become very important in relation to the true absorption coefficient.

Practical Applications

Metal Castings. This is the most important application of X ray industrial diagnosis simply because of the wide use of castings and because of the uncertainty of gross structure with empirically developed foundry practice. Figure 3 shows a radiograph of a typically defective steel casting. Thus far the radiographic method of testing has been devoted largely to the development of technic. However, where expensive machining operations are involved, examination of every piece is fully justified. The great value of this application is so obvious that an extended list of the achievements is unnecessary. Standard X ray equipment is to be found on German railroads, by means of which fire boxes and boilers may be examined in position.

Welds. Since there is no positive assurance by the usual methods that a weld has been made perfectly, it is not surprising that an X ray examination for soundness has become practically a necessary operation. Gas inclusions and pipe cavities easily are detected (figure 4). The practical result has been a vast improvement in the technic of welding within the past few years. Practically all manufacturers of welded pressure vessels in the United States are equipped with X ray apparatus and every weld is carefully radiographed. A new X ray unit (figure 5) to operate at voltages up to 300 kv, mounted on a traveling crane, is used to examine every weld made at Boulder Dam now under construction.

Miscellaneous Applications of Metal Radiography. In addition to castings and welds, numerous other types of metal objects may be subjected to X ray tests. These include all automotive and aircraft parts, rolled and drawn metal for the discovery of slag inclusions or overdrawing by cold work that is too extreme, inspection of insulated wires and cables and coated metals for breaks, metal tubes and capillaries for clogging, intricate assembled objects for proper adjustment of parts, projectiles for proper location of caps and fuses and complete filling by explosives, gun barrels for rifling and defects, molten metals inside of furnaces for the determination of melting point and surface tension, ball bearings for soundness, electric insulators for the presence of metallic particles, metal radio transmitting tubes for proper position of grid and filament, all sorts of sheets suspected of corrosion, steel Dewar flasks used for liquid air or oxygen where corrosion may result in great decrease in wall thickness, and many others. Following a fatal accident, all fencing foils at the University of Illinois are subjected to radiographic examination in the writer's laboratory, and shockingly poor metal structure in the sense of inclusions, cracks, and holes are



Courtesy General Electric X-Ray Corp.

Fig. 5. X ray unit in use at Boulder Dam for radiography of welds

discovered in many of the foils.

Other Miscellaneous Applications. Besides the inspection of innumerable metal products many other practical applications of radiography can be enumerated. Some of these are as follows: examination of arc electrodes for soundness; coal for classification as to foreign mineral content (see figure 6) and for control of cleaning by flotation; rubber tires for imperfect bonding to cords; reclaimed rubber for foreign material; golf balls for centering of core; complicated glass, hard rubber, and bakelite pieces of various kinds with internal seals for improper fabrication; wood for cracks, wormholes, knots, and imbedded nails; railroad ties for compression or erosion under the plates, porcelain insulators; thermocouple tubes; spark plugs for internal cracks; location of pipes and wires in the walls of buildings; contraband goods in trunks with false bottoms; suspicious packages for bombs; and many others. One of the most fascinating of these applications is to be found in the field of art. A well established branch of radiography is now the examination of old paintings and objects of art for evidences of retouching or of original paintings covered over with others, and for distinguishing true masterpieces from copies. An X ray photograph made of Rembrandt's portrait of himself recently indicated that under the visible head of the master was a portrait of an elderly woman wearing a cap. It follows that excellent X ray laboratories are now a standard part of the equipment of great art galleries.

Radiography by the Use of Gamma Rays. Presentation of the subject of industrial radiography would be incomplete without mention of the remarkable results obtained with the gamma rays from radium emanation. By this method 11 or more inches of steel can be penetrated, but the times of exposure are, of course, very long—from 12 hours up. However, the extreme simplicity and economy of the method involving the use only of a tiny capillary tube of radium emanation gas and the possibility of examining all sorts of fabricated structures in position make this a great contribution to the science. A great many interesting achievements already have been recorded in the United States and in Germany. Among these has been the successful detection of defective stern posts in new U. S. Navy cruisers. Further progress and applications will be awaited with greatest interest.

Analysis of Fine Structure of Materials

The most thoroughly interesting and probably the greatest branch of industrial radiology is the determination of the ultimate fine structure of materials from the results of diffraction analysis. The great practical importance of scientific knowledge of the ultimate structure of solids that are more or less perfectly crystalline in the natural state is evident when consideration is given to the definition of desired physical and chemical properties. The strength of steel girders, the forming of an automobile body, the corrosion of aluminum alloys, the breakage of an airplane propeller, the performance of a watch spring, the plasticity of lime, dielectric capacitance of materials, lubricating properties of long chained paraffins or graphite, improvements in the tensile strength of rayon, stretching of rubber, the covering power of pigments, the mechanism of the stretching or contraction of muscles and tendons, molecular differentiation between normal and pathological tissues, and innumerable other practical phenomena of everyday life all depend upon ultimate crystalline structure.

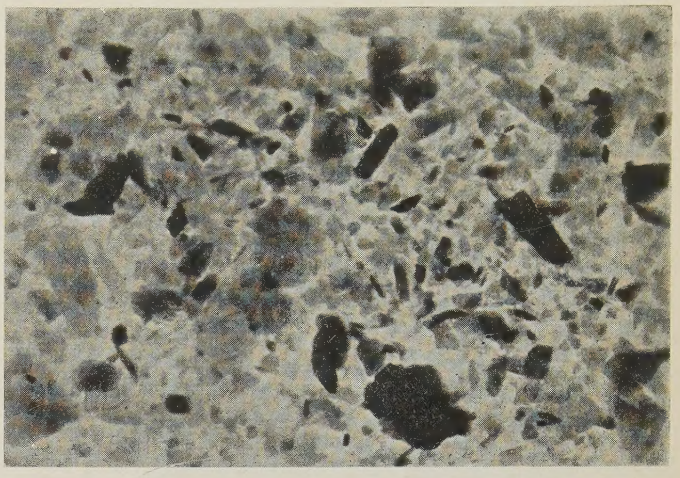


Fig. 6. Radiograph of raw coal showing heavily absorbing mineral impurities

The first aim of X ray analysis of the fine structure of a solid material is to determine the arrangement of atoms and molecules in the crystalline units and to account for the properties of the material in terms of that arrangement. The interference of X rays in gases and liquids has made possible more recently fine structure determination even for these states.

Röntgen and his contemporaries early attempted to demonstrate diffraction of the new rays which seemed to have so many properties similar to those of visible light. Diffraction of the rays by optical gratings could not be demonstrated, as is known now, only because of faulty experimental technic. It was 17 years after the discovery of X rays before interference phenomena in the case of X rays were demonstrated by Laue, Friedrich, and Knipping. When a fine pencil of X rays was passed through a crystal of zinc blende a definite and symmetrical pattern of spots was registered upon the photographic plate placed at a fixed distance behind the crystal. This so-called Laue pattern proved that all crystalline substances were constructed in a highly organized fashion in which the ultimate atoms and molecules were arranged on equidistant parallel planes. These imaginary planes evidently were spaced at distances of the same order of magnitude as the wave lengths of X rays. Consequently, any crystal serves as a 3-dimensional diffraction grating. Depending upon the kinds and arrangements of atoms or molecules, a characteristic diffraction pattern will be obtained which can be interpreted in

terms of the characteristic building plan of the particular material. The fundamental relationship was discovered by the Braggs to be $n\lambda = 2d \sin \theta$. In this equation λ refers to the wave length of the X ray beam, d is the spacing of any particular set of planes in the crystal, and θ is the angle of incidence. In all diffraction methods and with all types of equipment the experimental measurement consists in the evaluation of the diffraction angle 2θ. Since all crystals are built on so regular a lattice structure, it follows that 3 pairs of planes will enclose a small unit cell which will be the fundamental unit with all the properties of a crystal. Diffraction information will lead directly to the estimation of the size and shape of this unit cell, and from a knowledge of the density the number of atoms or molecules within the unit cell is established.

Geometrical considerations indicate that there are 230 ways of arranging atoms or molecules in space. Another way of stating this is that if the 32 point groups or combinations of symmetry operations be placed at the points of 14 space lattices, 230 space groups are obtained. It is the aim of X ray crystal analysis to determine uniquely the space group characteristic of each crystalline substance. A careful analysis of intensities of the various interferences on a diffraction pattern is required before the final

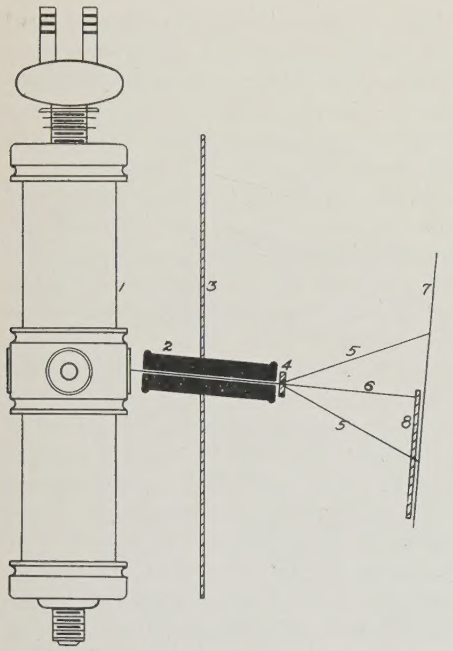


Fig. 7. Diagram showing arrangement for producing diffraction patterns

1. X ray tube
2. Pinhole system
3. Lead screen
4. Sample
5. Diffracted ray
6. Undiffracted ray
7. Photographic film
8. Lead screen to absorb undiffracted ray

selection of one out of all the possible space groups can be made. Each one of these space groups has certain definite criteria which are sought and established in the experimental diffraction data. Intensity data are analyzed further by trial and failure methods, sometimes involving the application of advanced mathematics such as Fourier's series analysis in order to determine the exact parameters of atoms and the positions of atoms within molecules. By such methods, for example, it has been established definitely that in benzene, naphthalene, anthracene, and other aromatic derivatives the so-called benzene ring, long familiar to organic chemists, actually exists in the solid form as a hexagonal arrangement of 6 carbon atoms which all lie exactly in the same plane with carbon to carbon distances of 1.42 Ångström units.

There are several experimental methods of diffraction analysis, but they all are directed to exactly the same end of measuring values of the angle 2θ. These various modifications are designed simply to utilize single crystals or finely powdered specimens. The most familiar of these methods are:

1. The Laue method in which a polychromatic X ray beam is passed through a stationary crystal mounted definitely with respect to the crystallographic axes.

2. The Bragg spectrometric method in which a monochromatic beam ordinarily is reflected from a single set of planes in a single crystal, as for example, from the cleavage face of a calcite crystal.

3. The powder or Hull-Debye-Scherrer method in which an essentially monochromatic beam is passed through or reflected from a specimen consisting of a fine powder or aggregate of very small grains (figure 7).

4. The rotation method in which the beam is passed through a single crystal rotated ordinarily completely around an important axis.

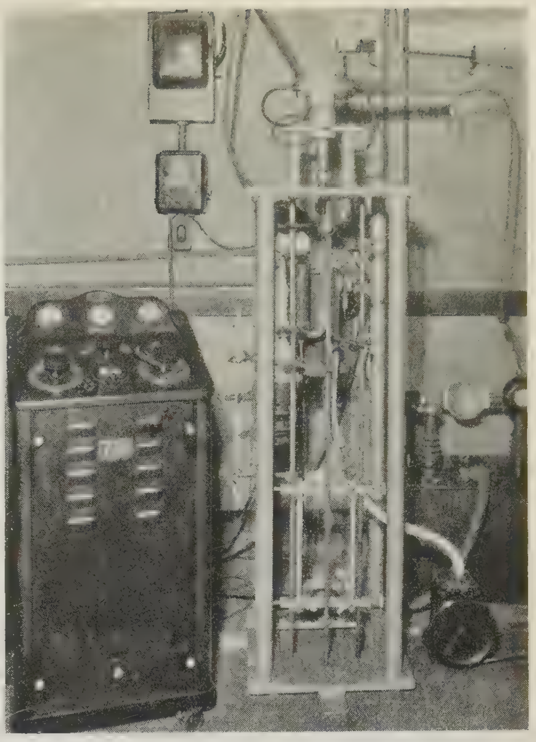
Excellent equipment is now available of universal and of multiple types by means of which interchangeable methods can be employed and several diffraction patterns photographed simultaneously from a single X ray tube. A photograph of such a modern diffraction apparatus is shown in figure 8. In practically all crystal analysis it was essential to have some information concerning the wave length λ of the X ray beam. Thus the predominating $K\alpha$ ray (really a close doublet) with a wave length characteristic of a particular target in the tube is utilized in all methods except the Laue method. The $K\alpha$ doublet is practically isolated by means of suitable filters. The target metals most frequently used are molybdenum with a predominating wave length of about 0.712 Ångström unit, which is suitable for studies of metals and inorganic compounds, and copper with a wave length of 1.54 Angström units, which is utilized for the study of organic materials. Voltages higher than 50 kv are not required or used. Consequently for purposes of attaining a very intense radiation which will cut down the necessary time for exposure to a minimum, diffraction tubes are designed especially to operate at high currents and also with minimum dimensions so that the specimen can be placed as close as possible to the focal spot. With some of the modern tubes, in which the beam passes through very thin windows, diffraction patterns may be photographed in a few seconds as compared with times of many hours or days required with the earlier types. Now when a diffraction pattern has been obtained for a given substance in solid state, whether in the form of a single crystal, powder, or any kind of aggregate of small crystals, grains, of sheet or wire, it may be measured and interpreted directly to the end of establishing the fundamental architectural plan, which then may be illustrated by large scale models.

It should be understood clearly that in this process accurate measurements actually are being made of distances of $^{1}/_{100,000,000}$ of a centimeter. The

Fig. 8. Apparatus for research on the structures of materials at the X ray research laboratory, chemistry department, University of Illinois

(Left) Multiple diffraction unit with X ray tube in upper small protecting cylinder and several pinholes

(Right) Complete unit for demountable X ray tube for producing beams of very great intensity

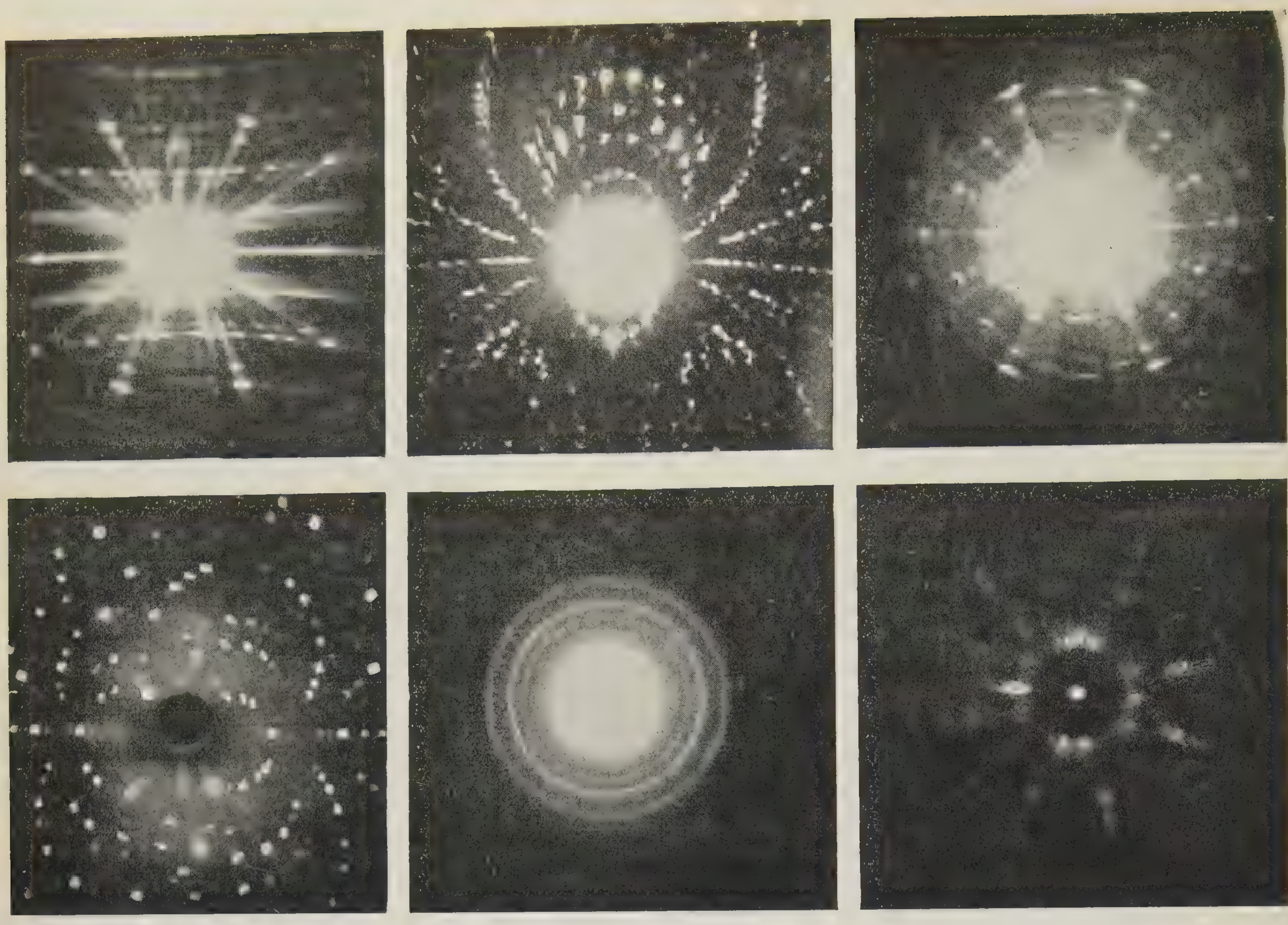


diffraction method then is, in a sense, an examination of ultimate fine structure with a supermicroscope. What appears to be homogeneous structure at the limit of resolution with the microscope, even with ultra-violet light, discloses a fine structure when subjected to the measuring rule of X rays.

As the results of the analysis of the structure of materials by means of X rays are surveyed, one is utterly amazed at the progress that has been made experimentally and at the great body of valuable facts concerning the building plan and behavior of materials heretofore unavailable. Some typical patterns are shown in figure 9. Nearly all of the chemical elements have been studied and their crystal forms classified, even some that are solid only at extremely low temperatures. It is perhaps fortunate that almost all of the familiar pure metals have very simple crystalline structures, either cubic or hexagonal. For example, some of the common metals like alpha iron, chromium, and tungsten are body-centered cubic, that is, the ultimate crystal cell unit is a tiny cube with an atom at each corner and one in the center. The ductile metals such as aluminum, silver, gold, copper, nickel, and lead are face-centered cubic, that is, the unit cell has an atom at each corner and one in the center of each face. Zinc, cadmium, magnesium, and other metals have a hexagonal close-packed structure. Some of the metals have more than one crystalline form, each being stable over a certain temperature range, as for example, iron, manganese, cobalt, and cerium. A few of the metals have very highly characteristic structure such as white tin, crystallized mercury, indium, and gallium. Besides the chemical elements, hundreds of inorganic compounds now have been analyzed. From these results it has been possible to ascertain something about the forces that hold atoms and molecules together, the shapes and sizes of different groups, and the explanation of every type of physical and chemical behavior. From a great mass of seemingly disconnected data has come a new science of crystal chemistry which has the greatest possible interest and significance. There is a perfectly sound reason why a given chemical compound should crystallize as it does. It would seem peculiar that there would be 16 ways in which inorganic compounds AB_2 should crystallize; but when the simplest geometrical conceptions of ratios of atomic radii are introduced to explain the packing of these minute units in space, a rational explanation immediately follows. In cases of exceptions there is good evidence in support of the fact that atoms may become deformed or are polarizable. The field of complex binary alloys may be taken as a very good example of modern trends.

Alloys, together with silicates, have been the bugbear of scientific exposition in terms of the usual chemical formulas, which might be expected. The formula for δ-bronze, for example, is $Cu_{31}Sn_8$. It is for such reasons that the alloy metallurgist has had to work empirically. Now with the results of X ray analysis, strictly scientific and rational classification is possible. The diffraction patterns for Cu_5Zn_8 (γ-brass), Fe_5Zn_{21}, $Cu_{31}Sn_8$, and others indicate the same type of structure—and they crystallize alike because the ratio of valence electrons to the number of atoms in the molecules is in every case 21/13 (Cu 1, Zn 2, Sn 4, Fe 0). Another whole series of intermetallic compounds crystallize alike because this ratio is 3/2 (β-alloys), and another with the ratio 7/4 (ϵ-alloys). The tremendous contribution of diffraction analysis to the field of alloys becomes apparent, since it leads to a knowledge of the whole constitutional diagrams, ranges of stability, discovery of new phases separating during aging or heating which are responsible for peculiar behavior,

Three varieties of the mineral asbestos



Single crystal of ammonium oxalate — Black diamond used in mining drills — Brass with poor structure cracked in auto radiator

Fig. 9. Typical X ray diffraction patterns of some common materials

and the prediction of properties in general. Similarly these rays have proved that in silicates with seemingly hopelessly complicated structures, oxygen atoms form the real network or backbone and all the other chemical elements appearing in the formulas are simply present in the holes of the oxygen network. Diopside is found to be built up of chains of silicon-oxygen tetrahedrons; asbestos is built from a doubled chain of the same kind, and mica in turn is the further sidewise coupling of chains into sheets—hence its characteristic cleavage.

In the field of carbon compounds besides the shape of the benzene ring already referred to, a great array of data is available with which the theories and models of organic compounds may be subjected to rigorous test. Of especial interest are the long-chain aliphatic compounds—hydrocarbons, fatty acids, alcohols, soaps, esters, greases, oils, and waxes. Diffraction patterns of thin films demonstrate a remarkable preferred orientation side by side of these long carbon chains, so that even the actual lengths of the molecules, as a function of the number of carbon atoms in the chain may be measured directly. Lubricating films in bearings then are characterized by oriented molecules which hold to the metal surface on one end, and slide over a layer of molecules similarly arranged on the other metal surface. Another practical application from the writer's laboratory is the study of the breakdown of high voltage cables. The whole process of molecular change, which consists in a polymerization or lengthening of the molecules of insulating oil originally present, is discovered and followed, where any other method would be futile.

Thus far consideration has been given only to the determination of crystalline architectural plan by means of X ray diffraction. An astonishingly long list of actual industrial achievements might be cited easily. Only a few of the materials and processes subjected to research and test are: lead oxides and storage batteries, minerals, clays and all ceramic materials, bone, gems, lime, cement, zeolites, electroplating, alloys of all types, petroleum products, drying oils, pigments, dyes, textiles (considered in a later paragraph), and rubber.

If the information obtainable from X ray diffraction results were limited purely to the question of crystalline structure, it is obvious that the method would fall short of greatest industrial usefulness. Many steel specimens under such circumstances would be expected to give identically the same lattice structure, but this would not be sufficient to demon-

strate why certain steel specimens perform satisfactorily and others are utterly unsatisfactory. It is one of the greatest achievements of X ray diffraction science that the exact condition of a given material also can be determined and the reason for a practical behavior demonstrated. In other words, the diffraction pattern gives convincing information concerning grain size, grain orientation, lattice distortion or strain, effects of mechanical work upon grain structure and orientation, and various other attributes of any given unit of a given material.

Information Concerning Grain Size. For a powder or random aggregate of and material in which the grain diameters are the order of 10^{-5} or $^{1}/_{1,000,000}$ of a centimeter, the diffraction pattern consists of a series of uniform continuous lines. If the grain size is larger than this these lines begin to appear spotted and these spots increase in size and become more random in distribution as the grains become larger. Careful research work in the writer's laboratory has demonstrated that the measured size of these diffraction spots is linearly related to the actual grain size. Consequently this range overlaps the microscopic range and the data obtained by the 2 instrumental procedures are fully consistent. There are many practical applications of this type of grain size measurement where the microscope cannot be used to advantage, especially inasmuch as specimens for the X ray study require no special polishing or preparation. If now the grain size becomes smaller than 10^{-5} centimeters, the colloidal range of particle sizes is involved. The diffraction lines become increasingly broader in proportion as the grain size decreases down nearly to the atomic dimensions of 10^{-8} centimeters. Consequently, a measurement of line breadth leads, by means of rigorous formulas which have been deduced to the evaluation of colloidal particle size, far more accurately than by any other method.

A further extension from the data properly interpreted is to the detection even of the shape of the colloidal particle. This is of greatest significance, of course, in the use of industrial materials such as carbon blacks in rubber compounding and in paint pigments. Colloidal graphite or carbon blacks may be prepared with particles of spherical or cubical shape or as thin flakes, or essentially a 2-dimensional particle, or as long tenuous almost unidimensional particles. These facts are differentiated clearly by these X ray measurements. Since most natural material such as proteins, cellulose, rubber, etc., are colloidal in nature, it follows that the estimation of colloidal particle size has been of great significance.

Grain Orientation. It is oftentimes advantageous to determine and to control the orientation of crystal grains in industrial materials with respect to some common direction, as for example, with respect to the surface of a sheet of silicon steel or the relationship of the crystallographic axis to the bearing surface in artificial sapphire pivots in watch movements. These orientations can be definitely distinguished and identified crystallographically by means of Laue diffraction patterns.

Effects of Mechanical Deformation. The diffraction patterns for metals and other materials that have been subjected to mechanical working such as drawing, rolling, torsion, stretching, or forging, are extremely interesting. Straightforward interpretation of such diffraction patterns proves that the mechanical forces have caused a realinement of small crystal grains originally at random into certain preferred directions. Thus in a cold drawn wire of aluminum the crystal grains all tend to turn with the body diagonals of the small unit cubes parallel to the axis of the wire or to the direction of drawing. Thus the pattern demonstrates not only qualitatively that a fiber structure exists, but a quantitative interpretation leads to the establishment of the exact mechanism and type of preferred orientation which usually is that which a crystal sets up in order to present maximum resistance to further deformation. Fiber patterns of fabricated materials of all kinds, therefore, have the greatest possible fundamental and practical significance, especially for metallurgical products. This includes also the possibility of preferred orientation of grains in electroplating where the final structure of the deposit as a function of the deposition variables can be ascertained accurately. In all rolled sheets, wires, bars, forgings, stampings, or in any material that has been stretched, bent, contracted, or deformed, we are just as directly concerned with a fiber structure as we are in a natural asbestos or cotton or wool fiber. X ray analysis of fiber structure is a whole science in itself.

Strain. One of the most important applications of diffraction analysis is in the detection of internal strain. Whenever crystal lattice planes become distorted or bent, the changed condition manifests itself in several different ways under the powerful scrutiny of X rays. The importance lies in the fact that there is no other satisfactory way of detecting a strained condition in the interior of opaque materials corresponding to the detection of strain in transparent materials by polarized light. Whenever a diffraction pattern is characterized by elongation of interference spots into radial streaks at random on the pattern, it is a clear indication of interior strain in the specimen. So many cases of failure in metallurgical and ceramic products especially can be accounted for easily since patterns of this kind can be obtained, whereas the microscope may disclose little or no indication of deficient ultimate structure. It follows at once, of course, that even greater practical utilization of diffraction information is to establish the absence of a distorted condition following proper heat treatment or revision of the processing in some detail.

Practical Metallurgical Results of Diffraction Analysis

Although X ray diffraction analysis is one of the newest sciences, a whole volume could be written already upon practical metallurgical applications. Of these the most important is probably the direct possibility of removing metallurgical heat treatment from the field of guesswork. It is the province of correct heat treatment of sheets of metal that are to be subjected to forming operations to remove com-

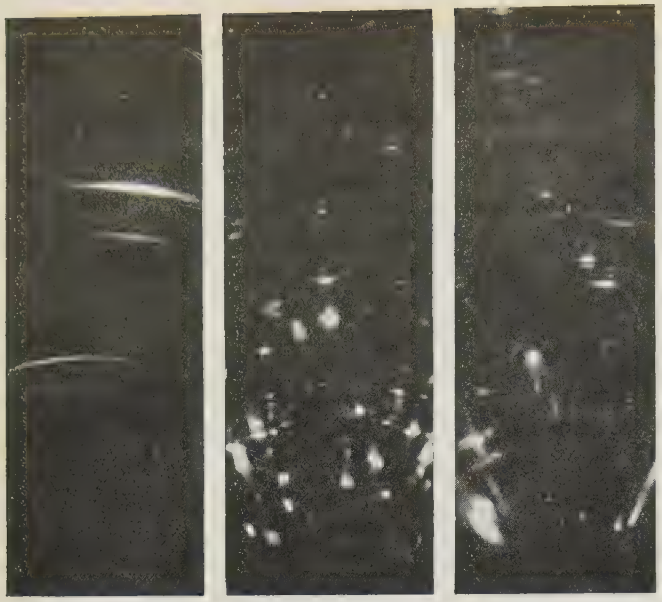


Fig. 10. Diffraction patterns showing changes in structure of aluminum alloy airplane propellers with use

(Left) Uniform metal in new propeller
(Center) Structure of same metal after 900 hours' flying showing marked grain growth
(Right) Development of strain after further use with danger of breakage and loss of life

pletely all traces of the original fibered structure introduced by rolling. Heating must eliminate also all evidences of strain such as are so common in castings. Hundreds of specimens have been submitted for examination in the writer's laboratory, of fabricated metals that have failed although apparently they had been treated in exactly the same way as products that have been satisfactory. Almost without exception the fault is to be found in faulty heat treatment. Case after case might be cited in which precisely the correct time and temperature of annealing has been established by simply following structure with X ray patterns. In watch springs, if the last trace of the rolled structure is not eliminated as detected by a single diffraction pattern, the spring is brittle and has what is technically known as fast motion. If the annealing treatment is taken just slightly too far and the recrystallized grains have grown slightly too large, the spring is soft and has a slow motion. The range between these, in which satisfactory springs are obtained, is exceedingly narrow, and the conditions must be controlled very exactly. It is not surprising that 50 per cent of all watch springs are unsatisfactory, although oftentimes this is not known until the spring has been incorporated into the watch movement.

Recently in the writer's laboratory a large number of new watch springs were examined with one diffraction pattern for each spring, and upon the basis of these patterns alone it was predicted how the spring would perform. These springs then were subjected to the usual manufacturer's tests and placed in watch movements. The predictions have been borne out to an astonishing degree. One common source of difficulty has been that the heat treatment may result in recrystallization; but instead of a random arrangement of the recrystallized grains, thus affording perfectly uniform properties for a sheet, the grains have taken up an entirely new preferred orientation, and consequently such a sheet will fail in forming operations.

Many interesting research results might be related for the study of gold alloy in fountain pen nibs, automobile steel, brass and copper sheets of all kinds, silicon steel for electrical purposes, defective structure in steel rails leading to transverse fissures, and amazing changes in structure with use and under the extreme conditions of fatigue of aluminum alloy airplane propellers. An extensive investigation now under way on the last named problem should go far toward preventing the loss of life that invariably accompanies the breakage of a propeller in the air. There is every indication at present that in those parts of the blades subjected to the greatest vibration and fatiguing forces occur the greatest structural changes (figure 10), including the deposition from solid solution of the intermetallic compound, $CuAl_2$.

These few examples must suffice to illustrate one of the most fertile fields for the application of research and testing by means of the X ray diffraction method.

Structure of Liquids and Amorphous Solids

The phenomenon of diffraction clearly depends upon some kind of regular arrangement of planes so as to constitute a grating. All crystals are built with such a plan. Many solid materials, long classified as amorphous because they appear so in the microscope, are genuinely crystalline in ultimate particles which X rays disclose. It hardly would be expected that liquids would produce any evidence whatever of ordered diffraction, but as a matter of fact they do. The patterns are characterized by only 1, 2, or 3 broad rings or halos, but these are evidence enough of some kind of transient but definite molecular arrangement. Stewart calls this cybotaxis. Extensive data are now available on the spacings in all kinds of liquids, which are a measure of molecular sizes and shapes, and thus permit the testing of theories of molecular structures. These molecular groupings which are "companies" in isotropic liquids are "regiments" in liquid crystals. In a true solution a single type of cybotactic group exists to which molecules of both solute and solvent contribute; for an emulsion such as phenol in water, diffraction halos appear for both constituents so that it is easily distinguished from a solution. An interesting extension has been the discovery of the orienting influences of electric and magnetic fields on liquids. Furthermore, the Harkins-Langmuir theories of definite molecular orientation at surfaces and interfaces of liquids are substantiated fully by diffraction studies. The newest triumph has been the explanation of the structure of a glass, an amorphous state of matter which produces only one or 2 diffuse diffraction halos. Around each silicon atom are definitely arranged *radially* other silicon

and oxygen atoms for a distance of 5.12 Ångström units, as in crystalline silica; but *around* these radii in azimuth there is statistically random arrangement.

Structure of Natural Polymerized Materials

In this class of materials are to be found all those of greatest biological interest as well as many of the most important industrial materials such as textile fibers. The X ray results indicate clearly, first, that these apparently noncrystalline materials are organized amazingly well or possess a crystalline constituent (figure 11), and that a common structural plan is utilized for such widely different substances as cellulose, proteins including silk fibroin, wool, hair, feathers, collagen, gelatine, nerve and muscle fibers, chitin from insect shells, rubber, gutta-percha, balata, and chicle. Briefly stated, this plan is as follows: Long primary valence chains or macromolecules are built up (or polymerized) from a relatively simple molecular group (or monomer), as for example dehydrated glucose residues $C_6H_{10}O_5$ in cellulose, isoprene C_5H_8 in rubber, and amino acid residues in peptide linkages in proteins. A bundle of these chains, which may be as long as 1.5 microns (molecular weight, one-half million), is held together by secondary forces to form the colloidal crystallite that recently has been isolated and identified for cellulose. The diffraction pattern of cellulose in wood, cotton, ramie, jute, hemp, sisal, flax, valonia, animal cellulose, etc., tells us that the unit monoclinic cell is 8.3 x 10.22 x 7.9 Ångström units and contains only 4 $C_6H_{10}O_5$ groups; that these groups are bound together in long chains by oxygen bridges; how long these chains are and how large the whole crystallite bundle is; and how these ellipsoidal particles are arranged in the fiber, whether in a random brush-heap fashion (as in cellophane) or in a nearly perfect alignment parallel with the fiber axis as in ramie (see figure 11).

In the writer's laboratory it has been possible to obtain direct measurements from interferences that appear when X rays of long wave length (magnesium $K\alpha$, 9.86 Ångström units) are utilized. It is by this technic that the first diffraction patterns from crystalline insulin were made possible. The unit cell dimensions from this familiar complex material are 80 x 100 x 130 Ångström units with 24 molecules having a molecular weight of 35,000 per unit cell.

Even the briefest account of achievements of scientific and practical significance in the study of these natural materials would run to a considerable length. It is safe to say that the improvements in the properties of commercial rayon noted in the past few years can be ascribed to X ray research.

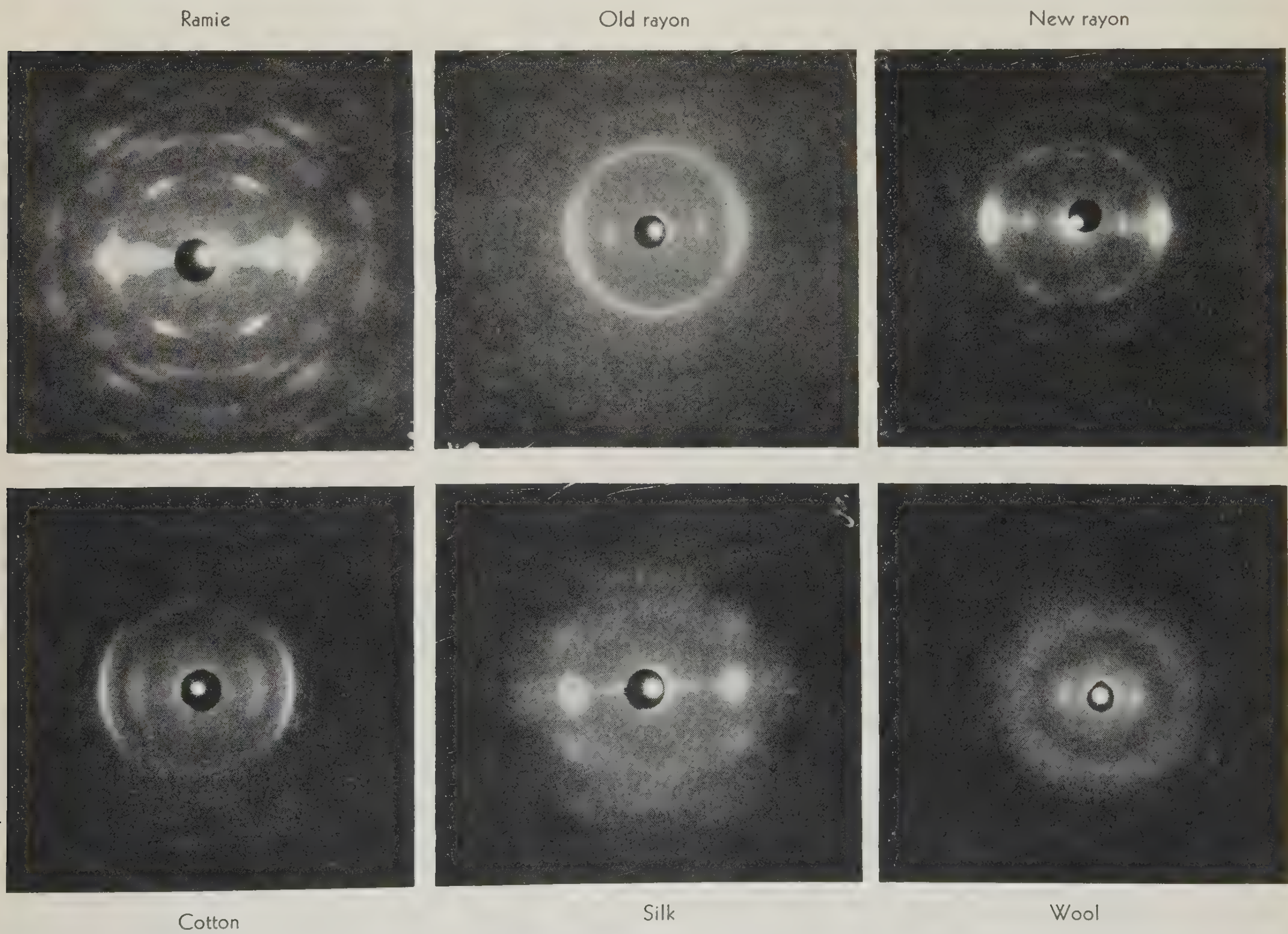


Fig. 11. X ray diffraction patterns of some typical textile fibers

The application of tension during coagulation of the regenerated cellulose alone led to greatly enhanced tensile strengths because the ellipsoidal particles were oriented in more perfect fashion. A highly oriented skin on a more random arrangement of particles on the interior is found. Stages of cotton growth and classification have been followed. Besides analysis of the crystalline structure of the remarkably beautiful and sharp patterns of natural silk, the highly oriented core and random skin are demonstrated. The faster the silkworm is forced to spin the fiber the more perfect is the preferred orientation. More has been learned about what rubber really is by analysis of the fiber pattern that appears when rubber is stretched than by decades of chemical research. This pattern is evidently the surest criterion of rubber molecular structure. A hundred synthetic rubbers have had a chemical composition identical with the natural product, but not one of these, until the discovery of duprene, gave a fiber diffraction pattern upon stretching—and the fundamental spacings in duprene are different. The identity of the hydrocarbon that exists in 2 polymorphic forms with a definite temperature of transition has been established in gutta-percha, balata, and chicle. The change in molecular form of protein chains in keratin fibers (hair, wool, quills, etc.) upon stretching has been shown strikingly from changes in the diffraction patterns. So Astbury has demonstrated a scientific procedure in permanent waving of hair; and in proofs of evolution theories in such facts as the structural similarities of feather keratin and turtle shells. X ray studies of catgut surgical sutures (collagen from sheep intestines) have led to greatly improved properties and uniformity.

Finally, we come to the structural studies of those materials of greatest medical interest, normal and pathological tissues. Fibrous collagen tendons, stretched gelatine, fabricated catgut sutures, and new work on living nerves are all analogous in showing a real though somewhat imperfect organization of complex protein molecules of great length. Muscle fibers, even studied in living frog legs excited to tetanus contraction, can be pulled into parallel diffracting alinement. An intensive study of fundamental molecular changes in normal and pathological tissues has been made in the writer's laboratory, with most promising results. Thus a great chemical and industrial science of X rays has brought back to medical science a third great use of the radiation that must be added to therapy and radiographic diagnosis, namely, the supermicroscopic vision of matter with its use in anatomy, pathology, and physiology, which the fundamental science of diffraction of radiation has afforded.

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Standardization of Noise Meters

A brief review of the present status of standardization of noise meters and measurements, and progress made to date by the technical committee on noise meters and noise levels of the American Standards Association.

By
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FELLOW A.I.E.E.

THE rapidly growing interest in noise reduction and the development work done by various industries to provide quieter apparatus to meet the public demand have created the necessity for consistent noise measurements. The standardization of methods of measurement and of units and scales for expressing the results are necessary first steps in arriving at standards for acceptable noise levels. These factors were important reasons that

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* Chairman, technical committee on noise meters and noise levels of the sectional committee on acoustical measurements and terminology of the American Standards Association.

Fig. 1. Substation on which the study was made

nature of most practical sounds. The range of sound energies to which the human ear will respond is so large that, on the average, a change of less than 25 per cent (1 decibel) cannot be perceived, and increases of 200 to 300 per cent (3.0 to 4.8 decibels) correspond to very moderate changes in loudness. Consequently, if in a practical example there are say, 3 sources of approximately equal importance, the complete removal of any one of them will reduce the energy by only 33 per cent (1.8 decibels) and the improvement is very slight indeed. The only effective procedure is, therefore, to determine the relative contributions from the various sources of sound and to devise reductions in *all* of the large contributors in order to bring about the required quieting. Reductions in the smaller components are obviously useless, so there is no point in working on them, nor in reducing any of the sources the noise from which is much below the general level. Sound measurements allow this to be done very effectively, and insure that important sources are not overlooked, nor effort wasted on unimportant ones. With data at hand on the results that can be obtained with various degrees of treatment of the individual pieces of equipment, one can compute with considerable certainty the results to be expected from any proposed change, and balance the comparative costs of obtaining various degrees of quietness, either at present or in the future.

This paper describes a series of experiments on the substation shown in figure 1 for the purpose of determining the noise levels existing in the neighborhood of the station and the reductions obtained by various quieting means. The sound sources in this case consisted of 9 200 kva and 1 120 kva self-cooled induction regulators in rooms inside the building and 2 6,000-kva 3-phase self-cooled transformers in the yard behind the building.

Experiments indicated that the noise, particularly that from the regulators, varied over a range of perhaps 5 decibels during the evening peak load, and, since time did not permit a study of all the variables of the problem, measurements were taken only between 10 a.m. and 4 p.m., except a few "shut-down" experiments which were made at about 2 a.m.

Preliminary tests indicated that so-called total-noise measurements, where all component frequencies of the sound are measured simultaneously, were not feasible for some of the measurements, particularly those some distance from the station, because of extraneous street noise. Although the analyzing ability of the human ear made the noise of the station distinctly audible in the presence of the street noise, even several hundred feet from the station, at these greater distances the latter often represented more energy and was, of course, very irregular so that it masked total-noise readings on the station. With the aid of an analyzing sound meter, the component frequencies of the station noise could be measured easily, and, accordingly, all measurements were made on these individual tones.

The quantity measured was the sound pressure; but since the ear is not equally sensitive to all frequencies, all the data of this paper have been translated to loudness level so that larger numbers represent louder sounds to the average ear. This was done by weighting the data according to the equal loudness curves of figure 2. If desired, the data can be changed back to physical units by the same curves. For example, a 100 cycle note of pressure 0.2 dyne per square centimeter (60 decibels above reference level of 0.0002 dyne per square centimeter) has a loudness level of 36 decibels, or a 200 cycle note of 40 decibels loudness level has a sound pressure of 0.045 dyne per square centimeter (53 decibels above 0.0002 dyne per square centimeter), etc.

Figure 2 is the same as figure 1 of "Proposed Standards for Noise Measurement" (Electrical Engineering, November 1933, page 744) except that the ordinate is called "sound pressure level" instead of "intensity level." This procedure is consistent with the proposed standards because, except for minor differences due to temperature and barometric pressure, the 2 terms are identical for plane and spherical sound waves, the only ones to which the standards refer. No standards have been proposed for sounds with interfering waves, which include essentially all practical sounds, but the proposal includes a defini-

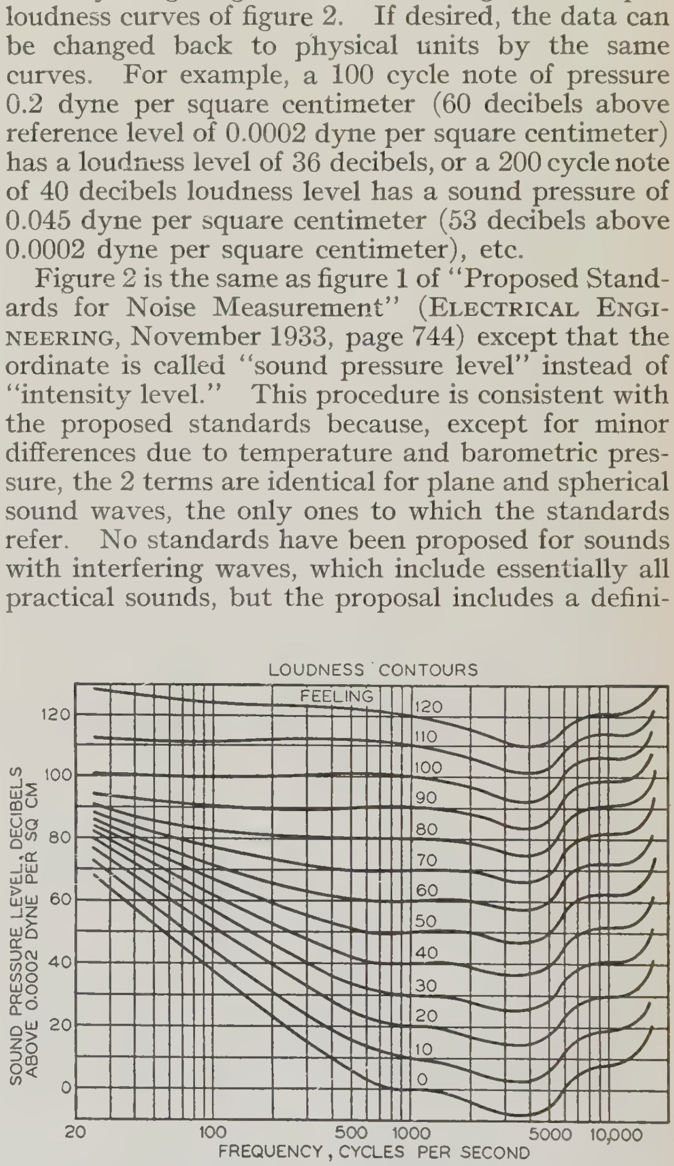

Fig. 2. Curves showing average characteristics of the human sense of hearing regarding relative loudness of tones of various frequencies and levels

These data were obtained at The Bell Telephone Laboratories and have been adopted as tentative standards by the American Standards Association (see Electrical Engineering, November 1933, page 744)

tion of intensity that makes it impossible to determine the intensity of a sound consisting of interfering waves by measurements with any meters known to the author. Since no provision has been made in the standards for expressing data taken with present-day meters in interference fields, this method, which is consistent with, but not authorized by, the proposed standards, has been used. (See "The Interpretation of Sound Measurements Used in Machinery Noise Reduction," E. J. Abbott, *Journal of the Acoustical Society of America*, January 1935.)

Table I—Loudness Levels of 120 Cycle Tone in Neighborhood of Substation, Decibels

Station	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Station	Line 3	Line 4	Line 5	Line 6
1	75	40	56	58	54	42	27	63	52	48	60
2	67	56	56	62	58	48	28	65	54	44	63
3	65	62	56	67	60	50	29	56	58	48	64
4	58	63	50	72	56	40	30	58	54	42	65
5	54	62	52	67	54	42	31	54	50	42	63
6	67	44	56	70	50	44	32	52	54	46	65
7	52	65	58	70	46	52	33	58	52	52	70
8	65	74	62	67	38	54	34	52	56	50	68
9	68	78	67	67	40	56	35	48	62	58	70
10		78	70	64	62	58	36	62	58	58	67
11		62	67	60	62	50	37	50	60	56	67
12		56	63	67	63	46	38	60	67	54	56
13		60	64	62	65	58	39	58	56	52	56
14		50	72	70	56	48	40	54	62	50	56
15		70	76	67	44	42	41	48	63	44	50
16		75	75	67	52	50	42	38	60	40	
17		73	72	67	48	50	43	36	65	38	
18		44	74	65	46	63	44	35	54	38	
19		70	78	65	48	68	45	33	60	42	
20		46	76	65	48	65	46		60		
21		67	75	58	50	63	47		46		
22		60	77	60	62	64	48		54		
23		54	72	60	60	67	49		60		
24		58	54	54	60	54	50		46		
25		38	67	54	56	65	51		58		
26			60	58	42	58	52		58		
							53		48		

Table II—Loudness Levels of 120 Cycle Tone at Different Heights Near Transformers, Decibels

Station	Transformer 1			Transformer 2		
	3 ft	6 ft	9 ft	3 ft	6 ft	9 ft
1	81	63	63	76	65	50
2	70			68		
3	68	80	60	73	70	35
4	75			75		
5	83	85	75	75	67	46
6	81			72		
7	77	80	60	67	62	58
8	67			70		
9	80	67	83	74	75	65
10	88			75		
11	92	85	81	76	78	67
12	93			72		
13	94	82	75	65	74	63
14	90			54		
15	89	76	68	52	65	64
16	88			65		
17	88	72	80	68	72	70
18	85			62		
19	83	80	73	54	72	63
20	75			67		
21	68	88	80	74	83	75
22	86			73		
23	86	88	82	68	80	67
24	78			52		
25	65	83	78	60	65	62
26	67			67		
27	77	63	67	70	72	72
28	80			67		
29	80	72	72	65	62	74
30	81			77		

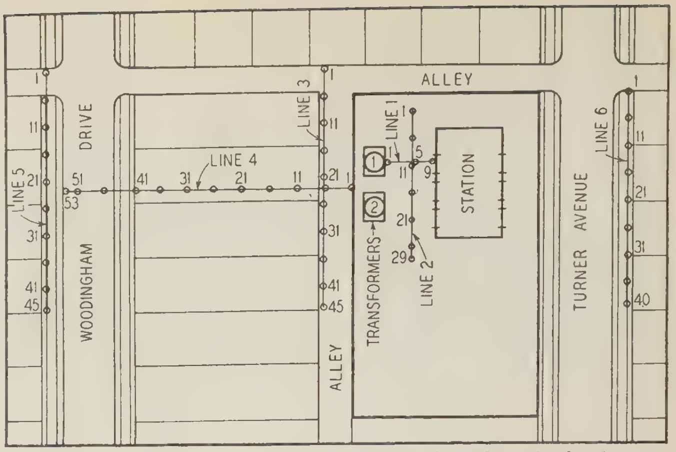

Fig. 3. General layout of the neighborhood of substation showing locations of lines of measurement stations. The stations were 3 feet apart, and the small circles indicate the location of every fifth station

Initial Survey of 120 Cycle Tone

Preliminary measurements both inside and outside the station showed that the noise consisted essentially of harmonics of 120 cycles per second, the odd multiples of 60 cycles being negligible. It was found also that in this particular case the 120 cycle tone was the loudest component. This is by no means a general conclusion for transformers and regulators; in fact, later measurements under other conditions showed that some of the higher harmonics were as important as the 120 cycle tone. Initially, however, the 120 cycle tone was predominant, and, accordingly, the first measurements were taken on it.

Six lines of measurement stations were laid out in the neighborhood of the station, as shown in figure 3. Readings of the level of the 120 cycle tone were taken at 3 foot intervals along these lines, with the microphone held 6 feet above the ground. The small numbers in the figure indicate the location of every fifth measurement station. The results of these measurements are shown in table I.

A second series of measurements was taken close to the transformers, which were about 10 feet in diameter and 12 feet high. Thirty equally spaced stations were laid out around the circumference of the transformers, and measurements taken at 3 different heights, 3, 6, and 9 feet. In all tests the microphone was held 8 inches from the transformer. These data are shown in table II.

Results of Initial Survey

The initial survey on the 120 cycle tone yielded 2 results: first, data on the distribution of the noise in the neighborhood of the station; and second, indication of the relative importance of various noise sources.

Distribution of 120 Cycle Noise. The outstanding feature of the measurements shown in tables I and II is the large and irregular variation in the loudness of the tone from point to point. Starting at any point in the neighborhood of the station and moving

Table III—Comparison of Averages of Measurements at Alternate Stations From Tables I and II

	Loudness Level of 120 Cycle Tone, Decibels	
	Odd	Even
Table I		
Line 1 (9 stations)	63	64
2 (25 stations)	61	59
3 (45 stations)	59	60
4 (53 stations)	59	60
5 (45 stations)	51	51
6 (41 stations)	57	56
Table II		
Transformer 1		
3 ft (30 stations)	81	80
6 ft (15 stations)	77	79
9 ft (15 stations)	76	70
General Average	78	76
Transformer 2		
3 ft (30 stations)	67	67
9 ft (15 stations)	70	71
9 ft (15 stations)	63	61
General Average	67	67

in any direction, the loudness did not remain essentially constant, or even increase or decrease regularly as the distance from the station was changed. Instead, in the matter of a dozen feet or so, the loudness ranged up and down by 20 decibels or more. These variations were not spaced uniformly, nor were the maximum or minimum values the same, although the reading at any single position was constant and ordinarily could be repeated within a decibel.

These point-to-point variations in loudness were clearly due to interference between the various direct and reflected waves of sound reaching the point of observation, and were particularly noticeable because of the long wave length (about 9 feet) and the constant frequency. Of course, they could be heard by ear as well as measured by meter. As shown in table II, these wave patterns existed right up to the surfaces of the transformers, the point-to-point variations on each transformer being approximately 30 decibels. This is attributed to the fact that the transformer shells do not pulsate as a unit, but instead the surface consists of many vibrating segments, each with its own phase and amplitude of motion.

As a result of these wave patterns, the data show some surprising facts. For example, transformer 1 is obviously much noisier than transformer 2; but at station 9, height 6 feet, transformer 1 measured 8 decibels less than the corresponding point on transformer 2. Also, the reading obtained at station 1 on line 4, about 10 feet from the transformers, was identical with that at station 52, on the far side of the adjacent street.

It would be an interesting, although somewhat laborious, task to plot these complex sound contours in 3 dimensions, but such data might be hard to interpret. While one might be interested in the location of the maximum values of loudness, particularly if one of them came at the head of his bed, it was thought that an average value of loudness for a given region would be of more value in this investigation. Accordingly, all conclusions were drawn from such averages. In the remainder of the paper, only these averages are tabulated, although the wave patterns were encountered in all measurements.

Accuracy of Averages. Obviously, when one attempts to average out variations of the order of 20 decibels or more, the accuracy of the results depends upon the number of values used, and the accuracy with which these values represent the range. One test of such averaging is to compare the averages of 2 halves of the data. Table III shows the results obtained by averaging the readings of alternate stations of tables I and II.

From the closeness of this check, it was decided that sufficiently accurate data could be obtained by taking measurements at every other station only, and this was done for the rest of the study. While these grand averages are probably correct within a decibel or 2, this accuracy does not apply to averages of smaller groups of measurements near transformers, etc. In such cases, it was suspected that the values might be altered by phase changes among the interfering waves due to shift of load, differences in reflections, or other causes. Accordingly, the tentative conclusions drawn from such figures usually were checked by subsequent measurements.

The average noise levels in the neighborhood of the station as determined from table I were as shown in table IV.

Relative Importance of Noise Sources. From this initial survey it was apparent that the noise levels on adjoining property on the back side of the station were determined by the transformers, not by the regulators. This is shown by table V, which gives averages of certain groups of readings in table I. The sound pressure was much greater in the alley than it was nearer the building, and also greater than it was at a corresponding position on the opposite side of the building, proving that it was due to the transformers.

The data also proved that the noise levels were determined by transformer 1, the noise from transformer 2 being negligible (see table VI). Transformer 1 was also louder on the side toward the alley than on the side toward the station.

Table IV—Average Noise Levels of 120 Cycle Tone in Neighborhood of Station

	Loudness Level, Decibels
In yard at rear, between station and transformers	60
In alley at rear of station	60
On sidewalk across street from front of station	57
On sidewalk on far side of street behind station	51

The range of values obtained in these various locations was approximately ±10 decibels above and below the average.

Table V—Averages of Readings Opposite Station Building

	Loudness Levels, Decibels
Line 2, in back yard between building and transformers (stations 5–24)	62
Line 3, in alley (stations 14–31)	68
Line 6, across street from front of building (stations 8–27)	57

These measurements furnished no information concerning the noise produced by transformer 2. While the measurements near it showed an average value of 67 decibels this is about the level of the remainder of the region resulting from noise from transformer 1 and the regulators. Hence, transformer 2 might be much quieter. It is hard to believe this when listening. When one placed his ear within a few inches of transformer 2, he seemed positive that the noise he heard came from it, but, as will be seen presently, such was not the case.

In making these comparisons of average levels, it should be kept in mind that if the pressure level of any component of a sound is 6 decibels or more below the level of the total sound, its complete removal will reduce the total by less than 1 decibel. If one component represents half the total sound, its removal reduces the pressure level by 3 decibels.

Experiments on Quieting Means

Shut-Down Test of Transformers. The initial measurements indicated that transformer 1 was the principal source of noise at the station; accordingly, arrangements were made to shut this unit down altogether for a short time and measure the resulting effect in order to obtain a more accurate measure of the relative importance of the other sources. This experiment was carried out at approximately 2 a.m., measurements being taken on line 5 on the opposite side of the adjacent street. Measurements were made under 3 conditions: both transformers on; transformer 1 shut down; and transformer 2 shut down. Averages of these measurements are tabulated in table VII.

A reduction of 29 decibels was obtained by shutting down transformer 1, proving beyond question that it was the principal source and that a large reduction would be obtained by replacing it with a transformer as quiet as transformer 2. To be consistent with this, the effect of transformer 2 on the total noise would have to be negligible; this was found to be true, the readings with and without it checking within the accuracy of measurement. This point having been proved, transformer 1 was replaced by a quieter one at this point in the investigation.

Experiments on Reducing Regulator Noise. Figure 4 shows the locations of the measurement stations

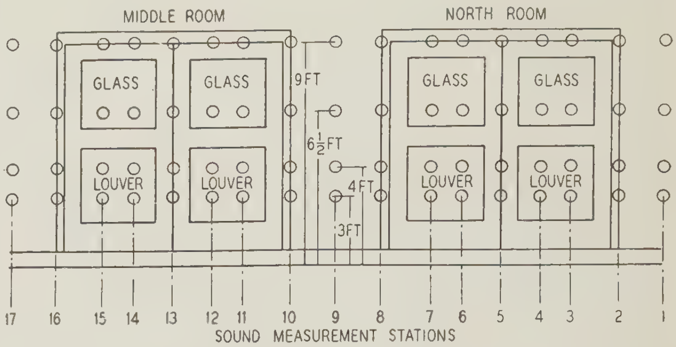

Fig. 4. Layout showing the locations of sound measurement stations near the doors of the regulator rooms on the front side of the station. The microphone was held 8 inches from the doors

used in testing the noise from the regulators on the front side of the building. The squares in the lower parts of the doors represent ventilating louvers, those in the upper parts, glass windows. Wave patterns probably were not averaged out as well in these studies as in the previous studies, particularly on the louvers, the dimensions of which were less than a half wave length; and it was suspected that changes in regulator settings might produce changes of pattern due to shifts in phase, or reflections that would affect readings considerably. For this reason, the readings probably are not as accurate as those previously described.

As shown in table VIII, it was obvious that most of the sound came from the louvers, as might be expected, the levels opposite these being even higher than near transformer 1. The obvious solution was to close these louvers and provide other ventilation for the regulators.

The company wished to test the effectiveness of several types of partitions in place of the outside doors of the regulator rooms. In order to do this it was essential that the noise level outside the doors would be determined by the noise coming through them rather than by noise coming from the other rooms, or by other paths. To test the extraneous levels, measurements were made with the regulators in the north room shut down. As shown in table VIII, this reduced the level at the louvers by about 30 decibels, but the level over the remainder of the door was reduced by only 13 decibels. With an uncertainty of measurement of 2 decibels or so, this precluded the possibility of testing partitions giving more than about 10 decibels reduction. As shown in figure 2, 10 decibels of loudness level corresponds to only about 5 decibels of sound pressure level at 120 cycles, which is a very small reduction factor for a partition. Hence it appeared useless to try to test partitions on one room, unless the other rooms were quieted also.

Table VI—Averages of Groups of Readings in Tables I and II Showing That Transformer 1 Was Principal Source of Noise

	Loudness Level, Decibels		
	Opp. Trans 1	Opp. Trans. 2	Opp. Bldg.
Line 2, in back yard	68	62	62
Line 3, in alley	75	61	68
	Sta. 10–19 Back Side	Sta. 26–30, 1–5 Front Side	Sta. 1–30
Transformer 1	81	72	77
Transformer 2	67	65	67

Table VII—Average Level of 120 Cycle Tone on Line 5

Condition	Average Loudness Level, Decibels
Both transformers on	54
Transformer 1 shut down	25
Transformer 2 shut down	53

Table VIII—Loudness Level of 120 Cycle Tone Near Regulator Doors on Front Side of Station

	Average Loudness Levels, Decibels		
	Louvers (8 Stations)	Remainder of Door (20 Stations)	Masonry Between Doors (4 Stations)
Middle room	83	68	65
North room	85	69	63
North room with regulators in north room shut down	55	56	

Table IX—Effect of Partition in Place of Outside Doors of Regulator Room on the Level of the 120 Cycle Tone Outside the Room

Louvers of other doors covered with steel plates. Readings represent averages of 20 stations inside and 24 stations outside. Wave pattern about ±10 decibels

	Average Loudness Level, Decibels	
Partition	Outside	Inside
Regular doors with louvers open: in front of louvers	83	
Regular doors with louvers open: remainder	64	85
Regular doors with louvers covered with 1/4-inch steel	54	87
Special partition *A*	54	88
Partition *A* plus regular doors with louvers covered with 1/4-inch steel	54 −	88
1/8-inch steel plate	48	85
1/2-inch "celotex"	60	85

Accordingly, the louvers on all the rooms on the north side of the station were covered by plates of 1/4 inch sheet steel, and measurements were made outside the station using the partitions listed in table IX. Measurements were made also at 20 stations inside the regulator room to check the effect of changes. The partition labeled *A* was made up as follows:

1/8-inch steel plate (inside)
1/4-inch air space
1/2-inch "celotex"
3/4-inch air space
1/2-inch "celotex"
1/4-inch air space
1/16-inch steel plate
1/4-inch air space
1/2-inch "celotex"

The air spaces were formed by wooden spacers at the edges, and the whole partition was bolted on the inside of the doorway with tight joints.

The measurements show that any one of the partitions, except the single layer of "celotex," was sufficient to reduce the noise to the point where the level outside the door was not determined by air sound passing through the partition. Apparently, the sound was due to vibration of the walls of the building, and in order to reduce this, vibration-reducing mountings for the regulators were indicated. Since it appeared that this expense would not be justified because of other noises, particularly that from the transformers, no tests were made of such mountings.

Another possibility of quieting is by installing sound absorbing material in the regulator rooms. While this did not appear promising, the large physical size of the source and wave length compared with the room dimensions indicated that computations based upon the ordinary reverberation formula were not justified; accordingly, to settle the question, the following test was made: Measurements were made of the noise level at 20 positions in one of the regulator rooms first in its usual condition, and then with 320 square feet of 1/2-inch "celotex" leaned against the walls. The 2 sets of readings agreed within a decibel; hence it was decided to spend no more time on this method, even though materials with larger absorption at this frequency might be obtained.

Measurements of Quieting Obtained by Transformer Replacement and Covering Louvers. Measurements were made on typical sections of the lines of measurement stations after transformer 1 had been replaced by transformer 1*A*, both with and without covering the louvers of the regulator rooms, to determine the reductions obtained and the relative importance of the sources under these conditions. The results are shown in table X.

These data indicate that replacing the noisier of the 2 transformers with a quieter one, and covering the louvers on the regulator rooms reduced average noise levels on neighboring property from 50 or 60 decibels to 20 or 25, which is a great reduction. According to data from the Bell Telephone Laboratories, this reduced the loudness (see figure 2 of "Proposed Standards for Noise Measurement," *loc. cit.*)

Table X—Data Showing Quieting Obtained by Replacing Transformer 1 and Covering Louvers

	Loudness Level of 120 Cycle Tone, Decibels		
	Transf. 1 and 2, Louvers Open	Transf. 1*A* and 2, Louvers Open	Transf. 1*A* and 2 Louvers Covered
Line 2, in back yard			
Sta. 5–23, opposite building	62	56	50
Sta. 7–13, opposite transf. 1 or 1*A*	68	54	48
Sta. 17–21, opposite transf. 2	62	60	52
Average of all readings in line 2	60	54	50
Line 3, in alley			
Sta. 15–31, opposite building	68	54	50
Sta. 17–21, opposite transf. 1 or 1*A*	75	56	50
Sta. 25–29, opposite transf. 2	61	52	50
Average of all readings in line 3	60	52	46
Line 5, on adjacent street	51	25	20
Line 6, across street from front of station	57	25	21

Table XI—Data on Relative Importance of Sources With Transformers 1A and 2, With Louvers to Regulator Rooms Covered

	Average Loudness Level of 120 Cycle Tone, Decibels			
Condition	Line 6, Adjacent Street Back of Station	Transf. 1*A**	Trans. 2*	Line 7, 8 In. From Covers on Louvers on Back of Building
Both transformers	20			
Transf. 1*A* shut down	19	46	62	
Transf. 2 shut down	17	52		54

* Measurements made at same positions as those in table II.

to about 4 per cent of its original value. When it is realized that street noise levels seldom fall below 35 decibels, even at night in residential districts (see "Results of Noise Surveys" by R. H. Gault, *Journal* of the Acoustical Society of America, July 1930, page 30) it is apparent that the 120 cycle tone usually will be completely masked and seldom, if ever, will be prominent.

Relative Prominence of Sources After Quieting. In order to determine the relative importance of sources after quieting, the experiments listed in table XI were made.

The data of tables X and XI show that, as far as the back side of the station is concerned, transformer 2 is the most prominent source of sound, and that the regulators with the louvers covered and transformer 1*A* are about equally important, the loudness level of the noise from each being several decibels below that of transformer 2. It should be noted also that the level near transformer 2 (see table II)was due to transformer 1 and not transformer 2. The actual level of transformer 2 was about 5 decibels less than the value given in table II.

Measurement of Other Component Frequencies

While the preliminary measurements indicated that the frequency of the predominant tone from transformer 1 was 120 cycles per second, the same might not be true after the changes mentioned in the preceding paragraph were made; accordingly, a few measurements were made of the other frequencies. For convenience, the transformer noise was analyzed at 10 stations near transformer 2, while the regulator noise was analyzed at 20 stations at a distance of 8 inches from each of 2 regulators selected by ear as being the noisiest and quietest in the station. The data are shown in table XII, the sound pressure measurements being converted to loudness levels by means of figure 2.

These frequency analyses show that, on the average, the loudest component in each is the 120 cycle tone, although because of wave patterns, it is likely that at some locations one of the higher harmonics is as loud. It is well known, as shown by figure 2, that at lower levels the ear is less sensitive to lower frequencies. Accordingly, at points some distance from the station, the higher frequency tones are relatively more important. The work of taking such measurements did not appear justified, because the practical problem already had been solved, but this effect can be estimated.

Assuming that all the tones are attenuated in the same ratio as the distance is increased, which seems quite reasonable, consider the region where the sound pressures are 0.1 as great as near the transformers (i. e., reduced 20 decibels). The corresponding loudness levels are shown in table XIII indicating that under these conditions, the 240, 600, and 720 cycle tones are louder than the 120 cycle tone. The conclusion to be drawn from these measurements is that it is not safe to assume which components of a sound are most important, but that actual measurements should be made.

Table XII—Frequency Analyses of Noise From Transformer and Regulators

Frequency, Cycles per Second	Average Loudness Level, Decibels		
	Transformer 2 (10 Sta.)	Regulator 4959669 (20 Sta.)	Regulator 5279613 (20 Sta.)
120	60	89	76
240	57	68	66
360	41	61	50
480	45	44	49
600	45	52	44
720	47	50	42
840	34	38	31
960	36	44	41

Table XIII—Frequency Analyses of Transformer and Regulator Noise Assuming All Sound Pressures 1/10 of Those in Table XII

Frequency, Cycles per Second	Average Loudness Level, Decibels		
	Transformer 2	Regulator 4959669	Regulator 5279613
120	22	60	40
240	28	44	38
360	16	36	25
480	22	21	26
600	23	30	22
720	25	28	20
840	12	17	10
960	16	24	20

Sound Measurements Give Definite Solutions

Conclusions reached from this series of measurements are obvious, in fact that is the principal advantage of sound measurements in industrial noise problems; arguments and matters of opinion are eliminated, the necessary lines of attack are indicated, and the results that can be obtained by various moves are determined. The second design of transformer was clearly much quieter than the first, and the fact that transformer 1*A* was noticeably quieter than transformer 2, even though they were supposed to be identical, was indication that more could be accomplished in this direction. Unless still quieter transformers could be obtained, or unless they could be enclosed, there was no point in quieting the remainder of the station more than covering the louvers of the regulator rooms. Better partitions than these obviously would be wasted expenditure.

The only question remaining was that concerning the most suitable means of providing ventilation for the regulators. A few experiments were made on baffles for the openings that would allow ventilation without allowing the sound to escape; but in the space available, it did not appear feasible to obtain the necessary muffling without too much reduction of ventilation. Accordingly, the louvers were replaced by steel plates, gratings were placed in the floor of each regulator room, and the air drawn in through the basement from an intake at the back of the station. This arrangement has been in use for nearly 3 years, and no complaints of noise from this station have been received during that period.

Wide Band Transmission Over Balanced Circuits

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Equipment for handling frequency band widths of the order of 1,000,000 cycles or more for telephone, telegraph, and television purposes was described in a recent Institute paper "Wide Band Transmission Over Coaxial Lines." This previous paper confines itself to the coaxial line structure, but points out that broad band transmission is also applicable to balanced conductor systems. The present paper discusses briefly some of the possibilities of the more familiar balanced circuits, circuits essentially as they now exist in the present plant being first considered, following which are considered circuits obtained by new construction. Wide band transmission over balanced circuits offers interesting possibilities both in the present plant and for new construction.

A HIGH degree of "electrical balance" has been for a long time a fundamental requirement of telephone transmission lines. This has been required not only to prevent interference entering into telephone circuits from other types of electrical circuits but also to prevent mutual interference between the closely adjacent telephone circuits on open wire lines or in cables.

As used here, the term "electrical balance" refers to the 2 sides of a telephone circuit. To secure such balance, the aim has been to construct the go and return conductors of each circuit of the same gauge and material and to locate them symmetrically with respect to earth and to surrounding conductors. The aim has also been to apply to each circuit terminal apparatus symmetrical with respect to its series impedances and shunt admittances to ground.

In the central offices, to be sure, unbalance in apparatus has been employed frequently for simplicity and convenience. In toll circuits, however, such office unbalance has been electrically separated from the outside plant by the use of repeating coils or otherwise. In local circuits the high standard of balance required for toll circuits has not generally been necessary since the exposures to interfering fields are less severe and the range of speech levels is much smaller. However, when local circuits are connected to toll circuits the unbalances are kept electrically separated from the toll circuits by the use of repeating coils. In recent years the tendency to the use of higher frequencies in communication circuits, the increase in the strength of interfering fields, and the development of highly efficient amplifiers has led to constantly more exacting requirements in electrical balance of telephone circuits.

The development of multichannel systems by carrier methods employing constantly increasing frequency ranges has placed particularly exacting requirements on such electrical balance. In a recent paper[1] on "Communication by Carrier in Cable" are described the balancing methods which have been developed to permit the use of an increased frequency range in such cables. The recently published paper[2] on "Wide Band Transmission Over Coaxial Lines" by L. Espenschied and M. E. Strieby points out the possibilities and possible requirements for very much wider frequency ranges. In that paper, coaxial lines are proposed which are particularly interesting in that they abandon electrical balance altogether and depend entirely on metallic shielding.

For such wide frequency range transmission, very interesting and important questions are raised, first as to the extent to which such wide bands can be placed on existing types of structure which are based on balance and, second, as to whether new construction designed particularly for such wide bands should depend on balance or shielding alone or a combination of the 2. It is the purpose of this present paper to discuss these questions.

As noted in the Espenschied-Strieby paper, the apparatus described for broad band transmission on concentric structures would also serve for other types of line structures. There would, of course, be problems in either balancing the apparatus or isolating its unbalances from the line structure. For the purposes of the present paper it is assumed that there will be no important reaction from the apparatus standpoint on this consideration of line balance and shielding.

Existing Cables

The attenuation of pairs in existing cables has a characteristic with respect to frequency generally similar to that of coaxial conductors but is, naturally, considerably higher because of the smaller physical dimensions and higher dielectric losses of the cable pair. For example, at 1,000,000 cycles an ordinary 19 gauge cable pair has an attenuation of about 18 decibels per mile, an ordinary 16 gauge pair about 14 decibels per mile, while a small sized coaxial structure

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1. For all numbered references see list at end of paper.

has an attenuation of about 6 decibels per mile. This means more repeaters for the cable pairs, 3 times as many for 19 gauge and a little more than twice as many for 16 gauge. Also, it means more difficulty in maintaining stability of transmission, including overcoming of the variations due to the effect of temperature changes.

Stable and highly linear repeater gain can be produced so readily nowadays, thanks to the negative feed-back amplifier invented by H. S. Black (see reference 3) that the idea of such high attenuations is no longer appalling even though on 16 gauge pairs it means repeaters spaced only about 4 miles apart. Overcoming the transmission variations due to temperature, with automatic regulators, introduces no fundamentally new problems, but, of course, the complexity and precision of regulation must be considerably higher due to the considerably larger variations.

Crosstalk, of course, must be given special consideration. First of all, it is necessary to restrict transmission of a given high frequency band to only one direction in a single cable; the other direction must be supplied by another cable[1] or other separate transmission medium.

Considering transmission in one direction only, if only one pair in a cable is set aside for high frequency transmission of, say, a million cycle band, most, but not all, of the crosstalk difficulty can be avoided. However, the fact must be reckoned with that if one pair in a cable is singled out and an amplifier is applied having 60 decibel or more gain at a point intermediate between voice-frequency repeater stations, the amplifier will have a strong tendency to sing due to crosstalk between the pairs connected to the input and output and the other pairs in the cable. If 2 cables are available, this difficulty can be avoided by jumping from one cable to another every time the high frequency amplification is introduced. If 2 cables are not available, overcoming the difficulty may call for the insertion of high-frequency choking devices in some or all of the low-frequency cable conductors at points where high frequency amplification is introduced.

Considering now crosstalk between 2 circuits in a cable transmitting in the same direction, assuming the amplifier difficulty to have been overcome, tests have been made on various cables in the field, from which these conclusions have been drawn. For telephone message purposes it is probably uneconomical to apply million cycle frequency ranges to more than a single pair in an existing cable. However, with television, the crosstalk requirements are much less exacting. This is because the range of intensities necessary for a good television image is much less than is needed to accommodate message telephone subscribers and, therefore, a considerably larger ratio of extraneous current to maximum signal current can be tolerated. Tests indicate that 2 or more television channels, each 1,000,000 cycles wide (possibly wider), can be transmitted over separate properly arranged pairs in the same direction in a single existing cable without serious disturbance due to crosstalk.

With respect to noise in existing cables, the matter of principal concern is noise produced in telephone offices by apparatus working on other circuits, since the natural shielding afforded by the cable sheath largely eliminates noise from outside sources. Two methods are available for control of the noise produced in telephone offices: (1) Introduction of high-frequency choking devices in all wires not assigned to carrier service at the points where the cables enter offices in which noise is produced; and (2) attack on noise at points where it is produced by introduction of spark-killers and individual high-frequency choking devices. The lenient noise-to-signal ratio requirement for television mentioned above makes high-frequency television application much easier than message telephone application.

While a million cycle frequency range over more than one pair in an existing cable seems unlikely for telephone message purposes, there are interesting possibilities in the use of lower maximum frequencies. For example, it seems likely that 12 same-directional telephone channels may be obtained from each one of a large fraction of the pairs in existing toll cables and that the crosstalk between the pairs may be kept within proper bounds by simple balancing methods previously described.[1]

Open Wire

With open wire, conditions are just about the reverse of those with cable. A mile of open wire has an attenuation of only about one decibel at a million cycles as compared to 6 decibels for the small sized coaxial conductor. However, overcoming crosstalk between different pairs of wires on a pole line presents very formidable problems, while avoiding interference from and to radio systems may be even more formidable.

The attenuation of open wire pairs has been checked up to several million cycles and it has been found that it behaves as expected. When there is little crosstalk from the high frequency band to other wires in the lead the attenuation-frequency characteristic is smooth; when there is severe crosstalk, the characteristic is bumpy. For a given length of circuit the attenuation is small compared with that of the small sized coaxial conductor and the variation due to changing weather conditions is also small—about $^1/_3$ that of the coaxial. It is interesting to note, however, that the percentage change in attenuation for the coaxial is less than half that for the open wire line. While it is, of course, evident that the open-wire transmission variations depend in part on changes in the series resistance of the wires due to changing temperature and in part to changes in leakage and capacitance due to varying weather conditions, automatic transmission regulating systems similar in general principles to those already developed for other purposes should be adequate to maintain the required stability.

Crosstalk between different circuits becomes so severe at high frequencies that special transposition treatment or respacing of the wires becomes necessary. Minimizing interference from and to radio systems calls for a high degree of balance which may or may not dictate changes in the wire configuration.

Here again it is necessary to distinguish between the requirements for television and for message telephone. Tests indicate that, in view of the more lenient television requirements, several million-cycle television channels can be transmitted over different pairs of a single open-wire line without serious disturbance and that to do this it will not be necessary to make radical changes in present wire configurations.

New Cables—Comparison of Different Types

For new construction, if television is not considered, effective carrier telephone systems may be set up by various methods. One might be a very broad band method, a good example of which is given in the Espenschied-Strieby paper. Another might be a much narrower band method using conductors similar to those in an ordinary cable. In the one case many telephone channels are obtained from a single pair by dividing up a frequency range, say 1,000,000 cycles wide, into somewhat more than 200 channels. In the other case only 20 odd channels are obtained per pair of wires and use is made of 10 pairs of wires to obtain the same total number. It is too early to say which of these plans might be best under various practical conditions.

To meet future television needs, it may be necessary to provide for transmission of continuous frequency bands 1,000,000 cycles in width or wider. It is interesting to compare the coaxial with balanced pairs surrounded by individual shields for such transmission.

For 6 decibel loss per mile at 1,000,000 cycles, it works out that a solid copper coaxial unit with the rubber disk insulation described in the Espenschied-Strieby paper has an internal diameter (inside of shield) of about 0.25 inch. For the same attenuation a pair of wires, each the same size as the central wire in the coaxial unit (70 mils diameter), insulated with rubber disks and with a copper shield, will have an inside diameter under the shield of about 0.4 inch. For outside conductors or shields made of lead the inside diameters become about 0.4 inch for the coaxial and 0.5 inch for the balanced pair. Therefore, if the thickness of the outer conductor is determined by mechanical considerations rather than outside interference, the coaxial is smaller and cheaper. As the frequency is made higher, the shielding from outside interference afforded by the surrounding cylinder increases, so that at very high frequencies mechanical considerations alone control and the coaxial is clearly cheaper than the balanced shielded pair.

In the frequency range up to about 1,000,000 cycles, however, interference from outside sources, including natural static and radio, must be considered in determining the thickness of the surrounding cylinder, and the cost comparison is not so clear. It will be evident that as regards shielding, the balanced pair is at a large advantage because the 2 sides of the circuit are designed to be electrically similar. By proper care in manufacture this balance readily can be made sufficient to insure adequate shielding with a surrounding lead tube of thickness determined solely by mechanical considerations.

With a coaxial structure, however, it appears likely that to keep interference within proper bounds, a simple lead tube must be made considerably thicker than required by mechanical considerations, so that such a structure would probably be more expensive than a lead shielded pair. However, by adding other materials an adequately shielded coaxial unit can be constructed which will have a considerably thinner outside wall.

For example, there is described in the Espenschied-Strieby paper a coaxial unit in which the inside diameter is minimized by first using copper tapes, the thickness of wall is minimized by adding thin iron tapes and the whole is made waterproof by a thin surrounding lead tube. This results in a unit of smaller inside and outside diameters than those of a lead tube surrounding a balanced pair of like attenuation. Since, however, the wall of the coaxial conductor is thicker and the structure more complicated, the costs of the 2 units are estimated to be not greatly different when they are designed for the frequency range up to 1,000,000 cycles. A minor advantage for the balanced pair remains, however, in that, whatever may be the top frequency, there is no limitation as to the lowest frequency permissible for interference reasons.

Other Considerations

In the above discussion of new cable construction the amplifiers and transmission regulators required have not been mentioned. If similar conducting and insulating materials are used, shielded balanced pairs and coaxials have similar transmission-frequency characteristics. The variations with temperature are also similar. The factors which limit the over-all amplifications are also the same. There is only one important point of difference between the amplifiers required for the 2 systems. This is the necessity for input and output transformers to be balanced to ground with the balanced pairs. The excellence of balance required, of course, depends upon the extent to which balance is relied on to reduce the required thickness of sheath. In view of the fact that very thin sheaths are impracticable for mechanical reasons it appears probable that only very modest requirements as to balance need be imposed on the design of these transformers.

To provide several circuits in new cables for meeting wide band television needs, another method may be considered, that is, to provide balanced pairs considerably larger in size than ordinary pairs and with the rubber disk form of construction, or other form giving low dielectric losses, but with no shields at all around the individual pairs. Shielding from outside disturbances would be provided adequately by the outside lead sheath of the cable. Crosstalk between different pairs would be the principal concern. If all of the high frequency pairs were to be used for television transmission, the crosstalk requirements, as already mentioned, would not be severe, so that by careful design the crosstalk could readily be kept within proper bounds—of course, restricting transmission of all wide frequency bands to a single direction within a single sheath. Such

high-frequency balanced pairs might prove suitable for telephone message circuits also. If not, the high frequency pairs would be restricted to television only, and other pairs, worked at lower frequencies, would be provided for telephone message service.

Summary

It appears feasible under certain conditions to transmit continuous frequency ranges of 1,000,000 cycles or more over conductors in the existing telephone plant. This may some day prove very important, particularly if the art of television develops to the point of calling for such wide frequency range circuits to carry television impulses around the country as sound programs are now carried.

For new construction, the balanced type of circuit, as well as the unbalanced coaxial circuit, offers many interesting possibilities.

References

1. Communication by Carrier in Cable, A. B. Clark and B. W. Kendall. Elec. Engg., v. 52, July 1933, p. 477–81.

2. Wide Band Transmission Over Coaxial Lines, L. Espenschied and M. E. Strieby. Elec. Engg., v. 53, October 1934, p. 1371–80.

3. Stabilized Feed-Back Amplifiers, H. S. Black. Elec. Engg., v. 53, January 1934, p. 114–20.

Cable System Neutral Grounding Impedance

Determination of the permissible neutral resistance or reactance for the grounding of cable systems for 3 phase power supply is considered in this paper. The theory of overvoltages which may arise as a result of intermittent arcs to ground through a cumulative action is discussed, and a description of the method for calculating these voltages is given. A simplified criterion for determining the value of neutral resistance or neutral reactance for limiting the overvoltages is proposed which permits the use of higher values than any preceding method.

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As power systems grow in generating equipment it becomes necessary to limit ground fault current to keep it within the rupturing capacities of circuit interrupting apparatus and to reduce the damage to operating equipment. Too much impedance in the neutral may permit the development of arcing ground conditions. This immediately raises the question as to what factors affect the choice of the value of impedance from this consideration and as to the maximum value of impedance that may be inserted in the neutral to limit the fault currents and still consider the system to be effectively grounded. It is the purpose of this paper to discuss this question and to offer for consideration:

a. A criterion upon which to base the choice of the neutral grounding impedance.

b. A method of calculating the limiting values.

Summary

It is proposed that the criterion for an effectively grounded system be based upon the requirement that calculated overvoltages from arcing grounds be kept down to harmless values. On this basis the following definition 15.10.153 has been proposed and is now being considered by the American Standards Association:

Effectively Grounded

Effectively grounded means grounded through a ground connection of sufficiently low impedance (inherent and/or intentionally added) that fault grounds which may occur cannot build up voltages dangerous to connected equipment.

This is a qualitative definition and permits those concerned with each class of apparatus to set their own quantitative limit which may be changed later if desirable. For cables, it has been tentatively suggested by the cable manufacturers and accepted by the operators that the calculated arcing ground voltages be limited to 3 times normal (crest to crest) line-to-neutral voltage. On this basis the following quantitative definition of an effectively grounded circuit can be set up:

Effectively Grounded Cable Circuit

A cable circuit may be considered to be grounded effectively if the maximum calculated arcing ground voltage under any operating condition does not exceed 3 times normal line-to-neutral voltage.

Resistance Grounded Cable Circuit

A cable circuit grounded through resistance will be effectively grounded in accordance with the foregoing criterion when the neutral

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grounding resistance is not greater than the value calculated by the following equation:

$R = 1.15\, X_o$

R = neutral grounding resistance

X_o = zero sequence capacitive reactance = $\dfrac{1}{\omega\, C_o}$

C_o = zero sequence capacitance
= $^1/_3$ capacitance of 3 conductors in parallel to ground

This expression may be written as follows in more familiar terms

$$R = 785\, \frac{\log\left(1 + \dfrac{2T}{d}\right)}{P}$$

or

$$R = 342\, \frac{G_1 S}{P}$$

The first expression applies to single conductors; type H cables; and single and 3 conductor, oil filled cables; the second expression applies to 3 conductor belted cables. In these expressions

T = thickness of insulation
d = conductor diameter
G_1 = geometric factor (Simmons)
S = sector correction factor
P = permittivity

Reactance Grounded Cable Circuit

A cable circuit grounded through reactance will be effectively grounded in accordance with the foregoing criterion when the neutral grounding reactance is not greater than the value calculated by the following equation:

$$X_n = X_1\, \frac{2 + p}{6}$$

where

X_n = neutral grounding reactance
X_1 = positive sequence reactance of systems
p = ratio of zero sequence reactance of system (exclusive of X_n) to positive sequence reactance

The definition and the proposed limiting values of resistance and reactance are based upon arcing ground overvoltages because these are affected by system grounding conditions, while overvoltages due to lightning and switching surges are not.

In either case the insulation at the neutral of the transformers or generators should be based upon the neutral shift—practically 100 per cent if the maximum permissible resistance is used, and $^1/_3$ line-to-neutral if the maximum permissible reactance is used.

Determination of Maximum Neutral Grounding Resistance or Reactance

Resistance. To make an exact calculation it is necessary to determine the total zero sequence capacitance of the systems. This can be done by calculation or by measurements. The zero sequence capacitance is the capacitance of one conductor to ground when all 3 are considered to be in parallel. To calculate it there is required a knowledge of the conductor size and thickness of insulation for each section of cable. In general this would be tedious and a simple approximation is proposed.

The application of the foregoing formula is greatly simplified by the use of a tabulation giving the permissible neutral grounding resistance for various circuit conditions in regard to circuit voltage and size and type of cable. The use of this tabulation is based upon the fact that precise calculations usually are not necessary and in some cases may not be possible, and upon the reasonable assumption that the various cable sizes in a cable system may be grouped together in zones for the calculation, without serious error in the resultant calculated neutral grounding resistance. By proper grouping the use of the tabulation in this manner may be made to give results that will be slightly conservative, i. e., the calculated resistance will be lower than the limiting value which might be found from an extended calculation using the formula.

The tabulation is shown in table I. In the tabulation the maximum neutral grounding resistance is given for 4 representative conductor sizes and for the various types of cable over the voltage range. The use of this tabulation as indicated will give results sufficiently accurate for the large majority of cases and if more precise results are required a detailed calculation may be made by direct use of the formula. Table I is used as follows:

The ohmic values in the tabulation represent the maximum permissible neutral grounding resistance for 100 miles of cable circuit for 4 sizes of conductors and various types of cable, and for permittivity factor $k = 3.7$.

The permissible ohms varies inversely as the length, so that values for other lengths may be obtained by multiplying the tabular value by $100/L$.

The permissible ohms varies inversely as the frequency, so that values for other frequencies may be obtained by multiplying the tabular value by $60/f$.

This tabulation may be used to estimate the maximum permissible neutral grounding resistance for any cable system based upon the estimated equivalent lengths of circuit in terms of the types and sizes of conductor listed in tabulation. For this purpose the cables approximately 1/0 in size and all smaller may be grouped as 1/0 conductor; the cables approximately 350,000 circular mils in size and

Table I—Resistance Grounding of Cable Systems

Circuit Voltage KV*	Type of Cable**	Neutral Grounding Resistance at 60 Cycles in Ohms for 4 Sizes of Conductors. 100 Miles of Circuit: 1/0	350,000 cir mils	750,000 cir mils	1,000,000 cir mils
4.1	*A-B*	37.6	22.4	16.7	10.6
	C	93.3	53.2	35.6	
6.9	*A-B*	47.1	28.9	20.6	13.8
	C	102.0	57.9	39.1	
13.8	*A-B*	64.1	40.3	29.3	20.0
	C	126.3	79.0	53.2	
23.0	*A-B*	81.6	53.0	39.3	27.2
	D	34.5	27.4	22.1	17.4
	E	56.9	35.5	25.4	
34.5	*A-B*	101.7	68.4	51.6	36.4
	D	43.1	34.6	28.0	22.1
	E	69.5	44.2	32.3	
46.0	*A-B*	115.5	79.7	61.0	43.6
	D	49.5	39.9	32.7	25.8
	E	78.4	50.5	37.4	
69.0	*A-B*	142.5	101.8	79.8	58.5
	D	63.7	53.0	43.1	34.4
	E	97.3	64.9	48.9	
138	*D*	94.1	78.8	66.6	54.5
	E	136.5	96.1	74.8	

* Insulation thicknesses according to 1934 standards of Association of Edison Illuminating Companies

** *A* = single conductor cable; *B* = type *H* cable; *C* = 3 conductor belted cable; *D* = single-conductor oil-filled cable; *E* = 3 conductor oil filled cable.

smaller, not included in the 1/0 group, may be grouped as 350,000 circular mils conductor; and similarly for the 2 larger sizes. The net effective value to be used is that obtained by considering the individual values all to be in parallel. For example, the neutral grounding resistance for an assumed 13,800 volt cable system is calculated in table II.

Arcing ground overvoltages are not the only factor to be considered by operating engineers in the selection of the value of resistance for grounding the neutral of a system. The final value to be used should be determined from consideration of a number of factors such as the rupturing capacities of circuit breakers, design of relay systems, and coordination with communicative circuits. After these factors have been considered and a desirable value of neutral grounding resistance selected a check should be made to see whether there is a chance that it is high enough to require the system to be classified as ungrounded. The tabulation offers a means of making this check rapidly and easily.

Reactance. To make an exact calculation it is necessary to determine the various system reactance values as for a short-circuit study. With these values in hand the determination of the limiting value of neutral grounding reactance for an effectively grounded system is a simple matter. For estimating purposes table III is given. This tabulation is used as follows:

The ohmic values in the tabulation represent the maximum permissible neutral grounding reactance for a 100,000 kva cable system based upon generator power supply $x = 0.15$ and transformer supply $x = 0.25$; the values are given for 2 values of system reactance. The permissible ohms varies inversely as the kilovolt-ampere capacity so that values for other kilovoltampere capacities may be obtained by multiplying the tabular value by (100,000 divided by the kilovoltampere capacity)

The maximum permissible neutral grounding reactance may be calculated directly from the following expressions:

$$x_n = \frac{2 + p}{6}$$

$$p = x_0/x_1$$

It will always be found that when resistance is used for grounding a much higher ohmic value is permissible than when reactance is used.

Sources of Overvoltage in a System

There are 3 sources from which overvoltages in a system might occur: lightning, switching, and arcing grounds. Lightning overvoltages occur only on exposed circuits and are limited in magnitude only by the line insulation at the point where the stroke occurs. The circuit voltage itself has nothing to do with the magnitude of the lightning voltage, except indirectly through the different insulation levels used for different voltages. On the other hand, switching surges are a direct function of the rated circuit voltage. Surge voltage recorder records over a period of years indicate that less than 2 per cent exceed 4.5 times normal line-to-neutral voltage. There is also some definite evidence that switching surges of the higher magnitudes are sufficiently fast as to have some impulse ratio. A study of the surge voltage recorder records obtained during the lightning investigation over a period of several years confirms the fact that both lightning and switching overvoltages are independent of the system grounding conditions. Therefore, they need not be considered in selecting the impedance to be used for grounding.

Table II—Sample Calculation of Resistance for a 13,800 Volt Cable System

Size	Type	Length, Miles	Neutral Grounding Resistance
1/0	A-B	35	(100/35) × 64.1 = 286
1/0	C	87	(100/87) × 126.3 = 145
350,000	A-B	178	(100/178) × 40.3 = 23
350,000	C	41	(100/41) × 79.0 = 193
750,000	D	31	(100/31) × 29.3 = 85
1,500,000	D	8	(100/8) × 20.0 = 250

The net effective value to be used is the parallel value of the separate values, i. e., 13 ohms.

Arcing ground voltages are affected by system grounding conditions and consequently should be considered in selecting the type and value of the neutral grounding impedance until such time as experience proves otherwise. Arcing ground overvoltages are also directly proportional to the system voltage. On an isolated neutral system they are independent of the extent of the system.

There have already been published 2 general explanations of the mechanism of the building up of the overcharges due to arcing grounds. In the first, the arc is assumed to go out at the first zero of the oscillation, and in the second, the arc is assumed to go out at the first zero of the normal frequency current. The first theory was presented by Dr. Petersen,[1] and the second by Peters and Slepian,[2] while Clem[3] extended the first theory and applied it to grounded neutral circuits. In general the oscillatory arc extinction theory leads to higher arcing ground voltages than the other, the theoretical maxima being 7.5 times and 3.5 times the normal line-to-neutral voltage, respectively.

This overvoltage is built up through a step-by-step process[1,3] and finally reaches a maximum limiting value which may be maintained for some time. When the initial arc strikes, the faulty line goes to ground potential and the 2 sound lines go to an excess potential above ground. When the arc goes out there is a charge trapped on the sound lines which does not drain off completely before the arc strikes again. As a result the trapped or bound charge increases each time and the sound lines rise in steps to successively higher values until the limit is reached.

Connecting an impedance from the neutral to ground gives a path over which the bound charge may escape and therefore reduces the possible overvoltages. Resistance is more beneficial than reactance because of the damping it causes.

A certain amount of skepticism exists in regard to the existence of arcing ground overvoltages. This is not surprising since it is rather difficult to understand how the arc goes out at the first zero of the oscillation, and staged tests have been made which failed to result in arcing grounds.

If there were no arcing ground overvoltages there would be no need for differentiating between the insulation used on an ungrounded system and that

1. For all numbered references see list at end of paper.

Table III—Reactance Grounding of Cable Systems

Circuit Voltage in Kilovolts	Neutral Grounding Reactance in Ohms at 60 Cycles for 2 Values of Positive and Zero Sequence Reactance. 100,000 Kva Capacity			
	x_1 = 15 per cent, x_0 = 1.5 per cent		x_1 = 25 per cent, x_0 = 11.5 per cent	
	x_1	x_n	x_1	x_n
4.1	0.025	0.009	0.042	0.017
6.9	0.072	0.025	0.119	0.049
13.8	0.286	0.100	0.476	0.195
23.0	0.793	0.278	1.322	0.542
34.5	1.786	0.625	2.975	1.22
46.0	3.178	1.115	5.29	2.169
69.0	7.15	2.503	11.9	4.88
138	28.55	10.00	47.6	19.52

x_1 = positive sequence reactance
x_0 = zero sequence reactance, exclusive of x_n
x_n = neutral grounding reactance

used on a grounded system. The reluctance of operating engineers in this country to use cables with the so-called "grounded insulation" on an ungrounded system is very good proof of the fact that cable failures have resulted from arcing grounds. The extensive use of the Petersen coil in Europe is evidence that they recognize the existence of arcing ground overvoltages. Also, early experience in this country with ungrounded systems has proved that they do exist, and flashovers from time to time on partially grounded systems, explainable in no other way, indicate that the possibility of arcing ground overvoltages should not be disregarded.

Criterion of an Effectively Grounded System

It is customary to use insulation on a cable depending upon whether the system was grounded or ungrounded. In the past when there was any appreciable impedance inserted in the neutral the system was generally considered to be "ungrounded" and the heavier insulation was required. However, in recent years the attitude has progressively changed and it has been required that a moderate amount of impedance may be used and still consider the system to be effectively grounded, that is, grounded so that there is no appreciable chance of dangerous overvoltages resulting from arcing grounds. Systems may be grounded directly or through an impedance, which may be resistance or a reactance. The following definition has been proposed and is now being considered by the American Standards Association:

Effectively Grounded

Effectively grounded means grounded through a ground connection of sufficiently low impedance (inherent and/or intentionally added) that fault grounds which may occur cannot build up voltages dangerous to connected equipment.

Whether or not a voltage is to be considered as dangerous depends upon the overvoltage that may safely be allowed. The arcing ground voltages are generally of appreciable duration, and accordingly the Insulated Power Cable Engineers Association has at present proposed to limit the calculated value to 3 times normal, and this has been accepted by the operating engineers as a basis for consideration. This is in reality quite liberal as far as resistance is concerned since it will give a value sufficiently high to limit the fault current to moderate values, and will give higher values than previously obtained with any generally accepted formula.

Since arcing ground overvoltages are affected by the system grounding conditions, while the overvoltages due to lightning and switching surges are not, only the former need be considered in setting up a criterion for an effectively grounded system. If the idea of arcing ground overvoltages was discarded altogether then it would not make any difference what value of resistance was used and there would be no need for a rule. However, it is wise to be conservative and go slowly in the matter and base the criterion on the analysis which calculates the highest voltages until such time as experience indicates that higher values of resistance may be used. Accordingly, the analysis based upon oscillatory arc extinction will be used, it being recognized that experience may later indicate higher values.

Method of Calculation

In one of the papers previously mentioned[3] a method is given for calculating the overvoltages produced by arcing grounds, which may be adapted to the problem of determining the limiting value of the neutral grounding resistance or reactance in consideration of the permissible overvoltages. This formula is as follows:

$$V_1 = \frac{3}{2} E \frac{(2-d)(3-2b) - \left\{1 + 2\frac{c}{c_m}\right\}(1-d)}{3 - 2(1-a)(1-d)} \tag{1}$$

in which

V_1 = maximum value of arcing ground voltage
E = system voltage line to neutral
$1-a$ = reduction factor which takes into account the part of the bound charge that leaks off to ground over the neutral grounding impedance
$1-b$ = reduction factor which takes into account the reduced neutral shift caused by the neutral grounding impedance
$1-d$ = reduction factor which takes into account the damping of the oscillation
c = average capacitance to ground of the 3 conductors
c_m = average mutual capacitance between pairs of conductors

Equation 1 can be simplified through the following considerations. In a 3 phase circuit using shielded cables or single conductor lead sheathed cables, c_m becomes infinite so that $\left(1 + 2\frac{c}{c_m}\right)$ becomes 1. In the paper[3] referred to, the factor $(1-b)$ is shown to be equal to the neutral shift ratio e_n. Making these substitutions in equation 1 there results, with a slight change in notation:

$$e_a = \frac{0.5 + e_n(2-d)}{1 - \frac{2}{3}(1-a)(1-d)} \tag{2}$$

in which the new terms are defined as follows:

e_a = ratio of arcing ground voltage to normal line-to-neutral voltage, i. e., V_1/E
e_n = ratio of neutral shift voltage to normal line-to-neutral voltage, i. e., E_n/E

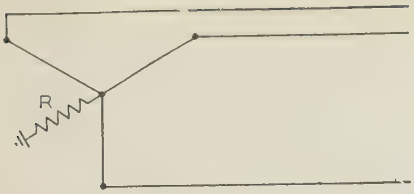
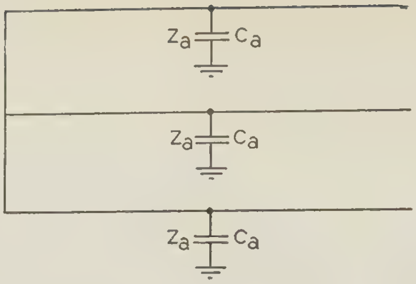


Fig. 1. Neutral grounding resistance, R



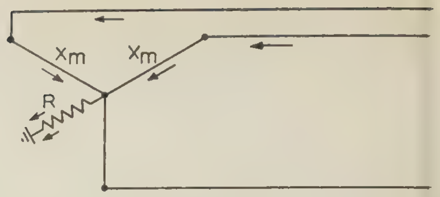


Fig. 3. Discharge path to earth of bound charge on the 2 sound lines, also discharge reactance, x_m

Fig. 2 (center). Zero sequence capacitive impedance Z_a and capacitance C_a

Dropping the factor c/c_m gives higher calculated voltages. Therefore, if equation 2 was used for 3 phase belted cables the calculated voltage e_a would come out higher than if equation 1 were used. Consequently limiting resistances for 3 phase belted cable determined on the basis of equation 2 will not be quite as high as might possibly be used. Since the resistances come out considerably higher than present practice, there seems to be no good reason for differentiating between the 2 types at the present time.

Evaluation of Reduction Factors

The reduction factors entering into this expression can be made to depend upon certain ratios, these are:

k = ratio of grounding resistance R used to the critical resistance r_n

$$R = kr_n \tag{3}$$

n = ratio of the zero sequence capacitive reactance x_a to the positive sequence reactance x_1

$$x_a = nx_1 \tag{4}$$

m = ratio of discharge reactance x_m to positive sequence reactance x_1

$$x_m = mx_1 \tag{5}$$

p = ratio of zero sequence reactance x_0 to positive sequence reactance x_1

$$x_0 = px_1 \tag{6}$$

The critical resistance r_n is that resistance in the neutral at which the discharge of the bound charge on the 2 sound phases to ground changes from oscillatory to nonoscillatory. It is defined by the expression

$$r_n = \sqrt{x_a x_m} \tag{7}$$

and x_m is defined by

$$x_m = \frac{2x_0 + x_1}{3} \tag{8}$$

For proof of equations 7 and 8 see development of equations 22 and 27.

The resistances and reactances mentioned in the previous paragraphs are defined as follows:

R = neutral grounding resistance. See figure 1
r_n = critical neutral grounding resistance
x_a = capacitive reactance of one phase when all 3 are in parallel with ground (sheath) return
= zero sequence capacitive reactance. See figure 2
x_1 = positive sequence reactance of system
x_m = discharge reactance. It is the reactance of one of 2 phases when the 2 are in parallel. See figure 3
x_0 = zero sequence reactance of systems

The positive and zero sequence reactances are the system reactances up to the point of fault which would be used in calculations to determine current for a ground fault. The zero sequence reactance of a cable is difficult of determination but fortunately it is usually a relatively small part of the total and therefore unimportant.

Usually the reactance x_1 and the charging current (corresponding to x_a) are expressed as percentages. If x is the per unit reactance and a the per unit zero sequence charging current,

$$x_1 = \frac{x\ \text{kv}^2}{\text{kva}}\ 100 \tag{9}$$

$$x_a = \frac{\text{kv}^2}{a\ \text{kva}}\ 1000 \tag{10}$$

And thus there follows

$$r_n = \frac{1000\ \text{kv}^2}{\text{kva}}\sqrt{\frac{x}{a}\ \frac{1+2p}{3}} \tag{11}$$

$$n = \frac{1}{ax} \tag{12}$$

$$m = \frac{1+2p}{3} \tag{13}$$

$(1-a)$ Discharge Leakage Factor

The reduction factor $(1-a)$ is the factor which takes into account the fact that part of the bound charge leaks off to ground from the 2 sound lines over the neutral grounding impedance. (See figure 3.) The discharge may be oscillatory or nonoscillatory, depending upon the circuit constants, but it is known in advance that for the resistance values which are of interest (the maximum limiting values) the discharge will be nonoscillatory. The general equation for the nonoscillatory discharge of a capacitor is:

$$(1-a) = \frac{e_c}{e} = \epsilon^{-\alpha t}\left(\cosh \beta t + \frac{r}{s}\sinh \beta t\right) \tag{14}$$

in which

e = initial voltage on capacitor
e_c = voltage at time t
α = damping factor

$$= \frac{r}{2L} \tag{15}$$

β = hyperbolic angular velocity

$$= \sqrt{\frac{r^2}{4L^2} - \frac{1}{LC}} \tag{16}$$

s = circuit impedance factor

$$= \sqrt{r^2 - 4\frac{L}{C}} \tag{17}$$

In this case the discharge is of 2 capacitors in

parallel (the 2 sound phases) and it will work out more conveniently if the constants for use in equation 14 are determined per phase.

r = resistance; it is twice the neutral grounding resistance plus the phase resistance. The equations will be simplified if the phase resistance is neglected, and if desired compensation may easily be made later on. Then

$$r = 2R \tag{18}$$

L = inductance; it is the inductance of one phase of the transformer or generator when current flows through two phases in parallel.

C = capacitance; it is the capacitance to ground and third conductor, when third conductor is assumed as grounded, of each of two conductors in multiple. For shielded cables it is the capacitance of the conductor to sheath, which is the same as the zero sequence capacitance. For belted cables this capacitance may be a little higher than the zero sequence capacitance. However, the zero sequence capacitance may be used since the omission of the factor $2\frac{c}{c_m}$ from equation (1) compensates for the difference.

Let

ω = normal system angular velocity

then

$$L = \frac{x_m}{\omega} \tag{19}$$

$$C = C_o = \frac{1}{\omega x_a} \tag{20}$$

When equations 18, 19, and 20 are inserted in 17 there results

$$S = \sqrt{4R^2 - 4x_m x_a} \tag{21}$$

When S becomes zero the discharge changes from nonoscillatory to oscillatory. The resistance which makes $S = 0$ is the critical resistance r_n so that

$$r_n = \sqrt{x_m x_a} \tag{22}$$

The reactance x_m is determined from the phase sequence theory as follows. (See figure 4—note that the subscripts used for equations 23 to 27, inclusive, are the conventional ones for phase sequence analysis and some may not agree with those used in the rest of the paper.)

$$I_a = i \qquad I_b = 0 \qquad I_c = i \tag{23}$$

$$I_{a0} = \frac{2}{3}i \qquad I_{a1} = -\frac{a}{3}i \qquad I_{a2} = -\frac{a^2}{3}i \tag{24}$$

$$e = \frac{2}{3}iZ_0 - \frac{1}{3}aiZ_1 - \frac{1}{3}a^2iZ_2 \tag{25}$$

$$\frac{e}{i} = \frac{1}{3}(2Z_0 - aZ_1 - a^2Z_2) \tag{26}$$

But Z_2 may be taken as equal to Z_1 without appreciable error and then

$$\frac{e}{i} = Z_m = \frac{2Z_0 + Z_1}{3} \tag{27}$$

The discharge period is assumed to last until the arc restrikes on the next maximum of the normal frequency, that is, during half of a normal frequency cycle. As an equation

$$t = \frac{1}{2f} = \frac{\pi}{\omega} \tag{28}$$

When the values of r, L, and C from equations 18, 19, and 20 are inserted in equations 15, 16, and 17 and these in turn with 28 inserted in 14 there results

$$(1-a) = \epsilon^{-\frac{R\pi}{x_m}}\left\{\cosh \pi\sqrt{\frac{R^2}{x_m^2} - \frac{x_a}{x_m}} + \frac{R}{x_m}\frac{1}{\sqrt{\frac{R^2}{x_m^2} - \frac{x_a}{x_m}}}\sinh \pi\sqrt{\frac{R^2}{x_m^2} - \frac{x_a}{x_m}}\right\} \tag{29}$$

which may be written in a briefer form

$$(1-a) = \epsilon^{-a\pi}\left\{\cosh \pi b + \frac{a}{b}\sinh \pi b\right\} \tag{30}$$

$$a = \frac{R}{x_m} \tag{31}$$

$$b = \sqrt{\frac{R^2}{x_m^2} - \frac{x_a}{x_m}} \tag{32}$$

If equation 30 is written in the exponential form it becomes

$$(1-a) = \frac{a+b}{2b}\epsilon^{-\pi(a-b)} - \frac{a-b}{2b}\epsilon^{-\pi(a+b)} \tag{33}$$

and the second part of the right hand term of equation 33 can be neglected without appreciable error, the error being such as to make the final result conservative. Then

$$(1-a) = \frac{a+b}{2b}\epsilon^{-\pi(a-b)} \tag{34}$$

The quantities a and b may now be expressed in terms of the quantities listed in equations 3 to 6 so that 33 becomes

$$(1-a) = \frac{k + \sqrt{k^2-1}}{2\sqrt{k^2-1}}\epsilon^{-\sqrt{\frac{n}{m}}(k-\sqrt{k^2-1})} \tag{35}$$

$(1-b)$ Neutral Shift Factor

The neutral shift when a fault occurs is the ratio of the voltage across the zero sequence impedance of the system to the normal line-to-neutral voltage. The voltage drop across the grounding resistance could be used but to be conservative the drop across the total zero sequence impedance will be used.

$$(1-b) = e_n = \frac{r_0 + jx_0}{r_0 + j(x_0 + x_1 + x_2)} \tag{36}$$

but

$$r_0 = 3R = 3kr_n = 3k\sqrt{x_a x_m} \tag{37}$$

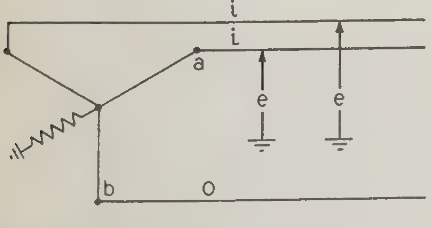
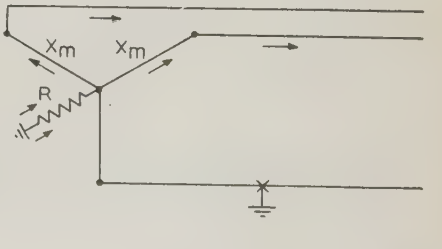


Fig. 4. Diagram for determination of x_m by sequence analysis

Fig. 5. Diagram for determination of neutral shift



so that using equations 36 and 3 to 6 there results

$$e_n = \sqrt{\frac{9nmk^2 + p^2}{9nmk^2 + (2+p)^2}} \tag{38}$$

(1−*d*) Damping Factor

The reduction factor (1−*d*) is the factor that takes into account the fact that the amplitude of the oscillation of the 2 sound lines when the arc restrikes is less than the applied voltage. The general equation for capacitor oscillatory charge is

$$\frac{e_c}{e} = 1 - \epsilon^{-\alpha t}\left(\cos\theta t + \frac{r}{q}\sin\theta t\right) \tag{39}$$

in which

θ = angular velocity factor

$$\theta = \sqrt{\frac{1}{LC} - \frac{r^2}{4L^2}} \tag{40}$$

q = impedance factor

$$q = \sqrt{4\frac{L}{C} - r^2} \tag{41}$$

and the other terms are the same as in the general equation for nonoscillatory capacitor discharge previously given.

The arc is assumed to go out at the first instant the oscillatory frequency current passes through zero and this corresponds to the instant of maximum voltage. At this instant $\cos\theta t$ is −1 so that

$$\frac{e_c}{e} = 1 + \epsilon^{-\alpha t} \tag{42}$$

from which it follows that

$$(1-d) = \epsilon^{-\alpha t} \tag{43}$$

In this case the neutral grounding resistance and one phase are in parallel and are in series with the 2 sound phases which also are in parallel. The process of getting this reduction factor into the same terms as (1−*a*) and e_n is as follows.

Referring to figure 5, the parallel impedance of the neutral grounding resistance R and one phase X_1 is

$$Z = \frac{RjX_1}{R + jX_1} \tag{44}$$

$$= \frac{R}{1 + (R/X_1)^2} + jX_1\frac{(R/X_1)^2}{1 + (R/X_1)^2} \tag{45}$$

so that the values of r and L to be used in equations 39 and 43 are

$$r = 2\frac{R}{1 + (R/X_1)^2} = 2R_0 \tag{46}$$

$$2\pi L = 2X_1\frac{(R/X_1)^2}{1 + (R/X_1)^2} + X_m \tag{47}$$

The figure "2" is put in to keep on a per phase basis. Equation 47 may be rewritten

$$L = \frac{X}{\omega} \tag{48}$$

$$X = 2X_1\frac{(R/X_1)^2}{1 + (R/X_1)^2} + X_m \tag{49}$$

(This designation of X is only temporary for the section under the side heading (1−*d*).) The capacitance is the capacitance of 1 phase of 2 in parallel to ground and the third phase when the third phase is at ground potential. This is the same as the zero sequence capacitance for shielded cables, and the zero sequence capacitance may be used without appreciable error for belted cables.

By proceeding as when developing the expression for (1−*a*) it is found

$$a = \frac{R_0\omega}{X} \tag{50}$$

$$\theta = \omega\sqrt{\frac{X_a}{X} - \frac{R_0^2}{X^2}} \tag{51}$$

Since $\cos\theta t$ is −1 the time is determined on the basis that $\theta t = \pi$ so that

$$t = \frac{\pi}{\theta} = \frac{\pi}{\omega\sqrt{\frac{X_a}{X} - \frac{R_0^2}{X^2}}} \tag{52}$$

and then

$$\alpha t = \frac{\pi}{\sqrt{\frac{XX_a}{R_0^2} - 1}} \tag{53}$$

which gives for (1−*d*)

$$(1-d) = \epsilon^{-\alpha t} = \epsilon^{-d} \tag{54}$$

$$d = \frac{\pi}{\sqrt{\frac{XX_a}{R_0^2} - 1}} \tag{55}$$

By using the relationships of equations 3 to 6 their results

$$R_0 = \frac{k\sqrt{nmX_1}}{1 + nmk^2} \tag{56}$$

$$X = mX_1\frac{1 + (2+m)nk^2}{1 + nmk^2} \tag{57}$$

and also there follows

$$d = \frac{\pi}{\sqrt{\frac{(1 + n(2+m)k^2)(1 + nmk^2)}{k^2} - 1}} \tag{58}$$

and so (1−*d*) is determined by equations 58 and 54.

Application

The grounding conditions are somewhat different when the ground is made through a transformer than it is when the ground is made through a generator because of the close coupling of the phases in a generator. In a transformer the zero and negative impedances are the same as the positive so that m and p are each unity. In a generator neither the zero nor the negative sequence impedance is equal to the positive sequence impedance. The negative is nearly equal to the positive and the zero may usually be taken as approximately 10 per cent of the positive.

In figures 6, 7, 8, 9 are shown curves giving the calculated arcing ground voltages for various values of neutral grounding resistance $R = kr_n$ and length of line $X_a = nX_1$. These curves can be used for estimating the maximum neutral grounding resistance for any given set of conditions as regards re-

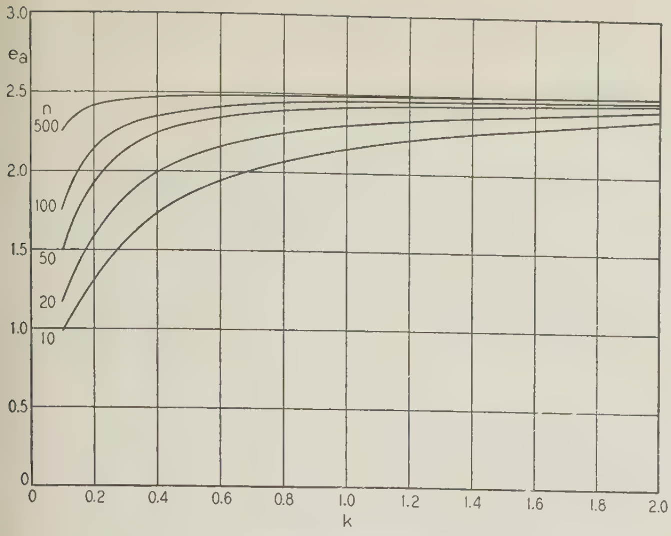


Fig. 6. Generator grounding; p = 0.1

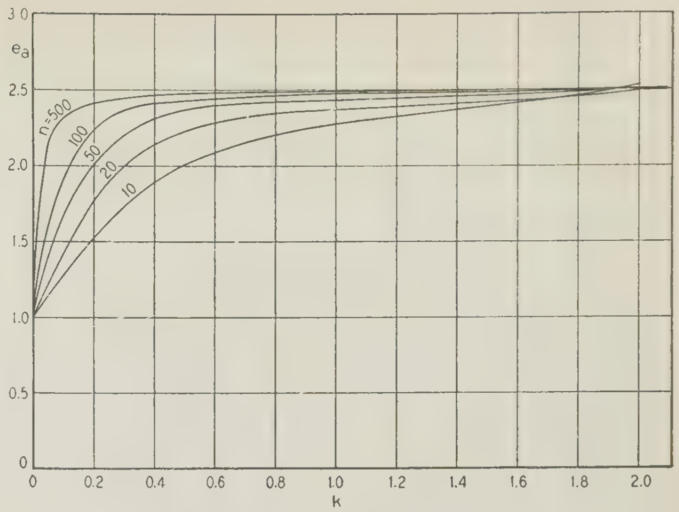


Fig. 8. Transformer grounding; p = 1

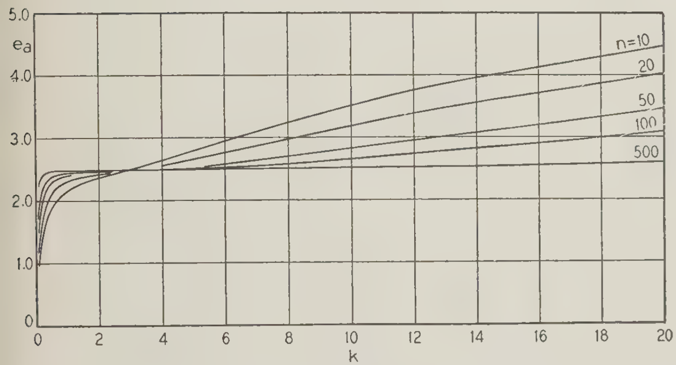


Fig. 7. Generator grounding; p = 0.1

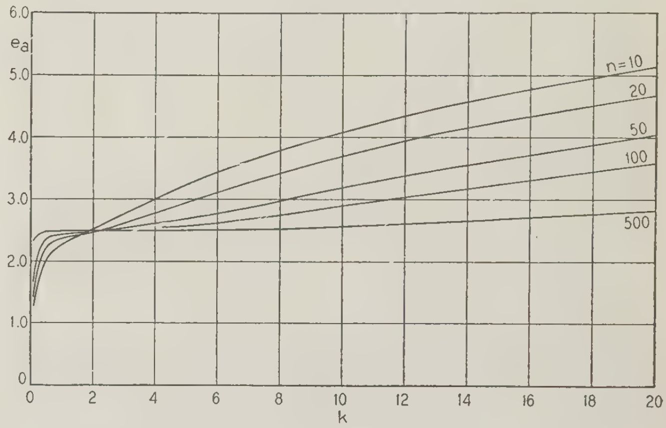


Fig. 9. Transformer grounding; p = 1

Figs. 6–9. Calculated values of the ratio e_a as a function of the ratio k for various values of the ratio n

E_a = ratio of arcing ground overvoltage to rated line-to-neutral voltage (crest to crest)
k = ratio of the neutral grounding resistance to the critical resistance
$n = \frac{X_0}{X_1}$ = ratio of the zero sequence capacitive reactance to the positive sequence system reactance

actances, permissible overvoltage, and length of of circuit. In making such calculations precision should not be expected.

For calculating these curves it was assumed that the total supply capacity (either generators or transformers) had grounded neutrals and that the point of fault was at the generator or transformer terminal. The zero sequence reactance of the generator was taken as 0.1 X_1.

The steps are as follows in using the curves:

1. Calculate X_1
2. Calculate X_0
3. Calculate p using equation 6
4. Calculate r_n using equation 7
5. Calculate n using equation 12
6. Determine k for p = 0.1 and p = 1.0 from the curves for allowable e_a and the given value of n
7. Interpolate between the values of k found to get the proper k for the given value of p and then multiply r_n by it to get R

The value of R thus found is the resistance which would be connected between the neutral and ground if all the neutrals were grounded at one point. If there are multiple grounding points then higher values may be used at each grounding point provided the multiple value does not exceed R and also providing that in case of separation no section is left with a resistance too high for its own conditions. To apportion the values for the different locations is largely a matter of judgment. The division might be made on the basis of generation, zero sequence reactance, total reactance; however, the best method is to apportion the grounding resistance in consideration of the possible capacitance combinations due to changes in length of connected circuit or disconnection of grounding points.

Development of Simplified Method

For an assumed system set-up, calculations made using the curves revealed that wide changes in generation had no effect on the limiting value of the

Table IV—Values of Multiplier of X_a in Equation 65

p	Ap	$\sqrt{\frac{1+2p}{3}}$	$A_p\sqrt{\frac{1+2p}{3}}$
0.1	1.85	0.632	1.17
1	1.15	1	1.15
2	0.95	1.29	1.23
Average			1.18

neutral grounding resistance. Only when the extent of the connected system was changed was there an appreciable change in R. The amount of work involved in the calculation using the curves can be eliminated by using an approximation which is developed as follows:

1. Points for k corresponding to an arcing ground voltage of 3 times normal for various values of n were read from figure 7 and figure 9 and plotted on log-log coördinate paper as a function of n. See figure 10, item 1. It was found that k could be represented as a square root function of n. As the curves are drawn they are conservative. This relationship was checked for $n = 500$ and found to hold. The equations are

$$k = 1.85\sqrt{n} \text{ for } p = 0.1 \tag{59}$$

$$k = 1.15\sqrt{n} \text{ for } p = 1.0 \tag{60}$$

Since the constant in these equations varies with p a general equation can be written as follows

$$k = A_p\sqrt{n} \tag{61}$$

(A_p = constant dependent upon p)

2. Calculations were made to determine the value of A_p for $p = 2$. For this the first step was to calculate e_a for $k = 6$ and $p = 2$, for a few values of n to determine the value of n corresponding to $e_a = 3$. The calculated values are plotted as item 2 on figure 10, and it is seen that when $e_a = 3$, $n = 40$. As a check the curves were drawn on semi-log and rectangular paper and values of $n = 40$ and $n = 38$, respectively, obtained. The next step consisted in calculating A_p for $n = 40$ and $k = 6$ from the square root law. From equation 61

$$A_p = \frac{k}{\sqrt{n}} \tag{62}$$

This gives $A_p = 0.95$ for $E_a = 3$ and $p = 2$.

3. The third step consisted of a simple mathematical transformation as follows. As previously stated

$$r_n = \frac{1{,}000\,\text{kv}^2}{\text{kva}}\sqrt{\frac{X}{a}\,\frac{1+2p}{3}} \tag{11}$$

from which

$$r_n = X_a\sqrt{ax\,\frac{1+2p}{3}} \tag{63}$$

also

$$k = A_p\sqrt{n} \tag{61}$$

from which by substituting equation 12

$$k = A_p\sqrt{\frac{1}{ax}} \tag{64}$$

As also stated,

$$R = kr_n \tag{3}$$

Now substituting equations 64 and 63 in this last expression for R, there results

$$R = X_aA_p\sqrt{\frac{1+2p}{3}} \tag{65}$$

4. The fourth step consisted in determining the value of the multiplier of X_a in equation 65 for the 3 values of p as in table IV.

Consequently the expression

$$R = 1.15\,X_a$$

is a reasonably close approximation for the calculation of the maximum neutral grounding resistance for the condition that this maximum calculated arcing ground voltage shall not exceed 3 times the normal line to neutral voltage.

The expression

$$R = 1.15\,X_a$$

can easily be put into another form which permits a direct calculation of R without the necessity of intermediate steps.

The standard equation

$$C = \frac{0.03882}{\log\frac{D}{d}} \text{ millifarad/mile} \tag{66}$$

when $2T + d = D$ is substituted becomes

$$C = \frac{0.03883}{\log\left(1 + 2\frac{T}{d}\right)} \tag{67}$$

But

$$X_a = \frac{1}{2\pi fc} \tag{68}$$

so that, R for 100 miles of line is given by

$$R = 785\,\frac{\log\left(1 + \frac{2T}{d}\right)}{k} \tag{69}$$

And also the standard equation

$$C = \frac{0.0169\,nk}{G} \text{ millifarad/1,000 feet} \tag{70}$$

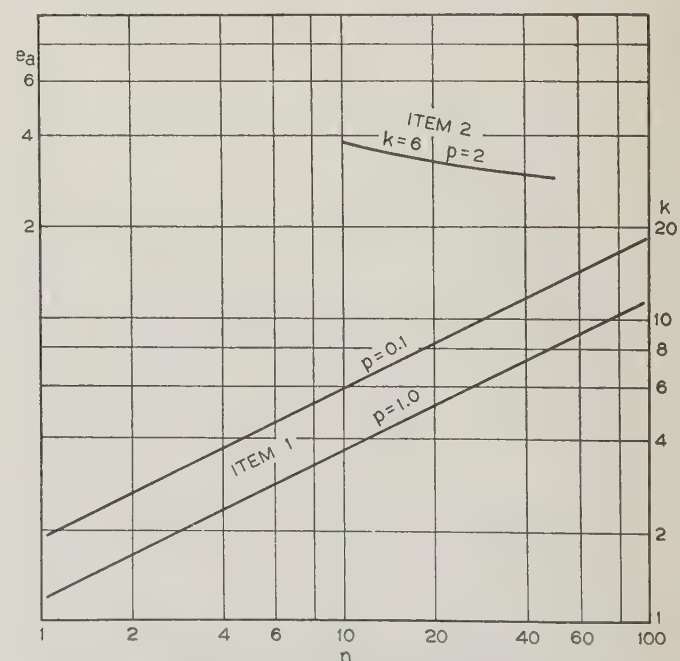


Fig. 10. Chart for the determination of the final expression, $R = 1.15X_a$

gives through the same process for 100 miles 3 phase belted cable

$$R = 342\,\frac{G_1 S}{k} \tag{71}$$

the factor S is the sector correction factor. Since the capacitance per conductor is concerned the number of conductors n cancels out.

In this section, equations 66 to 71, the nomenclature, except R, is the same as in the "Underground System Reference Book" (published by the former National Electric Light Association) pages 297–9.

Comparison With Previous Methods

There have been other methods considered previously for determining the maximum permissible neutral grounding resistance. Lewis[4] suggested that the Petersen coil principle be applied, i. e., make the lagging component of the fault current with resistance grounding equal to the charging current in the fault. Later, Clem suggested that the critical resistance be the criterion for resistance grounding. In view of the widespread discussion and comparison of the Lewis method and the critical resistance method, a comparison of the 2 will be made.

When a ground occurs the current in the fault is

$$I_f = \frac{3E}{Z_0 + Z_1 + Z_2} \tag{72}$$

$$= \frac{3E}{\sqrt{r_0^2 + X_s^2}} \tag{73}$$

$$X_s = X_0 + X_1 + X_2 \tag{74}$$

and the lagging component is

$$I_x = \frac{3EX_s}{r_0^2 + X_s^2} \tag{75}$$

In one of the references[3] it is shown that the charging current in the fault is

$$I_c = \frac{3E}{X_a} \tag{76}$$

Now equate

$$r_0 = \sqrt{X_a X_s}\sqrt{1 - \frac{X_s^2}{X_a^2}} \tag{77}$$

and since $r_0 = 3R_w$

$$R_w = \frac{1}{3}\sqrt{X_a X_s}\sqrt{1 - \frac{X_s^2}{X_a^2}} \tag{78}$$

(R_w = maximum possible neutral grounding resistance on the basis that with a resistance grounded neutral the lagging component of the current in the fault be equal to the leading component)

By the critical resistance method the limiting resistance would be, from equation 7,

$$R_c = \sqrt{X_a X_m} \tag{79}$$

Divide equation 73 by equation 72

$$\frac{R_c}{R_w} = \frac{3}{\sqrt{1 - \frac{X_s^2}{X_a^2}}} \tag{80}$$

Thus, it is seen that the critical resistance method should always give the higher values, providing the calculations are consistently made.

In table V is given a comparison of the Lewis method, the critical resistance method, and the present proposed method. This tabulation is based on data furnished by D. W. Roper. Comparing items 2, 4, and 6, it is quite obvious that the method proposed in this paper permits the use of higher values

Table V—Calculation of Maximum Permissible Neutral Grounding Resistance on a Chicago Cable System

Chicago System Studied	9 Kv	Crawford Station 12 Kv	66 Kv "Red"	66 Kv "Blue"	66 Kv Total
1. Using table of April 17, 1933					
a. Total LK (millifarads)	438	288	17	14	31
b. Total kva (in thousands)	209	424	1,000	1,000	1,000
c. Number of neutrals used	2	2	3	3	5*
2. Resistance calculated from Lewis' formula (ohms)		6	42	47	50
3. Resistance used in Chicago (ohms)	2.5	3	30	30	30
4. Resistance calculated from Clem's** formula (ohms)	6.95	10.6	179	218	110
5. Resistance calculated by critical resistance method (ohms)***		7.9-10.4	55-73	62-81	65-86

* If the 2 66 kv systems in Chicago, which are normally operated separately, were tied together, then the procedure would be to use only 5 of the 6 grounding resistances.

** Based upon LK values in tabulation.

*** Based upon proportionality to Item 2.

The data for items 1, 2, and 3 were furnished by D. W. Roper.

of neutral grounding resistance than any preceding method. This is desirable in addition to the additional advantage of being much simpler in application.

Maximum Neutral Grounding Reactance

When reactance is used for grounding the neutral the determination of the maximum permissible value is much simpler. In this case the factors $(1-a)$ and $(1-d)$ are very nearly unity. If a value of 0.95 is assigned to them it can be shown that the permissible calculated arcing ground voltage of 3 times normal line-to-neutral voltage gives a limiting neutral shift of about 0.36 E. This limiting condition can be attained by setting a limit of the ratio of neutral grounding reactance to positive sequence reactance. The desired conditions will be obtained when the ratio of the neutral grounding reactance to the positive sequence reactance is calculated from the following expression:

$$\frac{X_n}{X_1} = \frac{2 + p}{6} \tag{81}$$

where

X_n = neutral grounding reactance
X_1 = positive sequence reactance of system
p = ratio of zero sequence reactance of system (exclusive of X_n) to the positive sequence reactance.

Insulation at the Neutral

There are cases where a saving may be made if the insulation at the neutral be reduced when the system is grounded. Whether or not any reduction might be made for an effectively grounded system depends

upon the method of grounding. If the system is grounded through resistance and the maximum permissible value used then practically full neutral shift occurs and full insulation will be required at the neutral. If the system is grounded through reactance the conditions are such that the neutral shift is limited to $^1/_3$ normal line-to-neutral voltage and it might be possible to use reduced neutral insulation.

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Industrial Electronic Control Applications

Electronic tubes are being applied in rapidly increasing numbers in the solution of industrial control problems. A review of several of the most frequently encountered types of problems to which these tubes are being applied is presented herewith. These include photo-electric control applications, electronic relays, electronic regulators, and a welding timer for seam welding.

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WHEN the first electronic devices were brought on the market, it was often found that the applications were made indiscriminately, and electronic equipment was used on account of its novelty, in applications where mechanical or electromagnetic equipment previously had proved a success and was entirely adequate. At this stage of electronic development, most industrial engineers seemed very enthusiastic over the possibilities of electronic control, and the various electrical manufacturers received inquiries about electronic equipment for nearly every type of control operation. Gradually, however, it was more generally realized that electronic equipment was not destined to supplant the electromechanical and mechanical types of control apparatus entirely; and a sounder conception of the utility, scope of application, and importance of electronic equipment in the field of industrial control was attained.

The development of electronic equipment for industrial control has progressed so rapidly during the last few years that this type of equipment now, generally speaking, has passed the experimental stage and industrial application engineers are compelled, when planning new installations, to consider the advantages of electronic control as compared with electromechanical control equipment.

Considering the future of industrial control equipment, it should be realized that electromechanical control devices long have been manufactured more or less on a mass production basis, and the cost of manufacturing this type of equipment cannot be expected to be much reduced. In regard to electronic control equipment, however, it is not unreasonable to expect a reduction in manufacturing costs, as the general activity of electronic control equipment is increased. The cost of electronic tubes is at present a major item in the total cost of electronic equipment, and the cost of tube replacement in many cases prohibits the application of an electronic device, which, for purely engineering reasons might have been desirable. Reduced tube cost, brought about by quantity production of industrial electronic tubes, and possible increased tube life as a result of im-

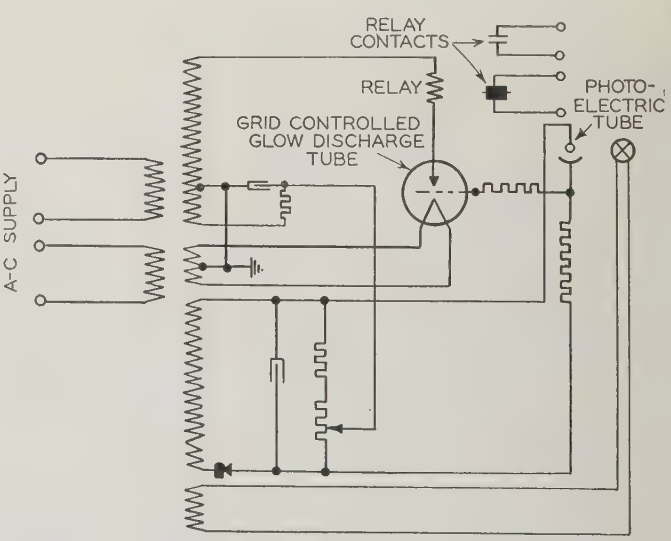

Fig. 1. Schematic diagram of photo-electric controller

Of the 2 relay contacts shown in the upper right-hand corner of this diagram, the upper one indicates a contact open when the relay is deënergized and the lower symbol indicates a contact which is closed when the relay is deenergized. These symbols are used throughout the diagrams of this paper

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provements in tube design, undoubtedly will change the picture of industrial applications and help to move the center of gravity over toward the electronic side.

I. Photo-Electric Control Applications

In many industrial control operations it may not be possible to use either mechanical or electromagnetic means to obtain the desired indication. This may be caused by the fact that the variations in the quantity to be controlled cannot easily be converted into mechanical or electrical forces, or, if this can be done, the energy available may be too low to operate any of the conventional mechanical or electromagnetic control devices. The photo-electric tube has proved a valuable tool in many of these industrial control applications.

The simplest type of photo-electric equipment, not considering the photo-voltaic cells, consists of a photo-electric tube connected to control a grid controlled glow discharge tube as shown in the schematic diagram in figure 1 and in figure 2. The grid controlled glow discharge tube amplifies the feeble current of the photo-electric tube to a value which will operate sturdy relays and contactors. The photo-electric controller may be connected so that the type *KU*-627 tube will break down and energize the relay if the illumination on the photo-electric tube is increasing or it may be connected to energize the relay if the illumination is decreased. A typical application of this photo-electric controller is the counting of moving objects when it is undesirable or inconvenient to use mechanically operated counters. Applications which have been made include counting automobiles at toll bridges, persons entering a movie theater, freshly painted objects moving on a conveyor, mail bags on conveyor systems, and hot steel ingots.

One of the first industrial photo-electric applications was the paper break indicator, and this application is representative of the type where methods requiring mechanical force would not be practical. During normal operation of a paper machine, the operators may all be working at one end of the machine, and some time may pass before a break is noticed. In the meantime paper will be piling up at the section where the break occurred, and production losses will result. Installation of a photo-electric controller as a paper break indicator will cut the outage time, and will in most mills prove a very advantageous investment. Light-sensitive devices have been employed to some extent in steel mills to initiate shearing operations or as a flag switch. Due to the pounding of the hot metal on the flag switch the maintenance of such a switch is often prohibitive. Furthermore a light-sensitive flag switch cannot cause cobbles such as are frequently started by the failure of the mechanical flag switch, or by the force exerted by the flag bending over the end of a steel sheet.

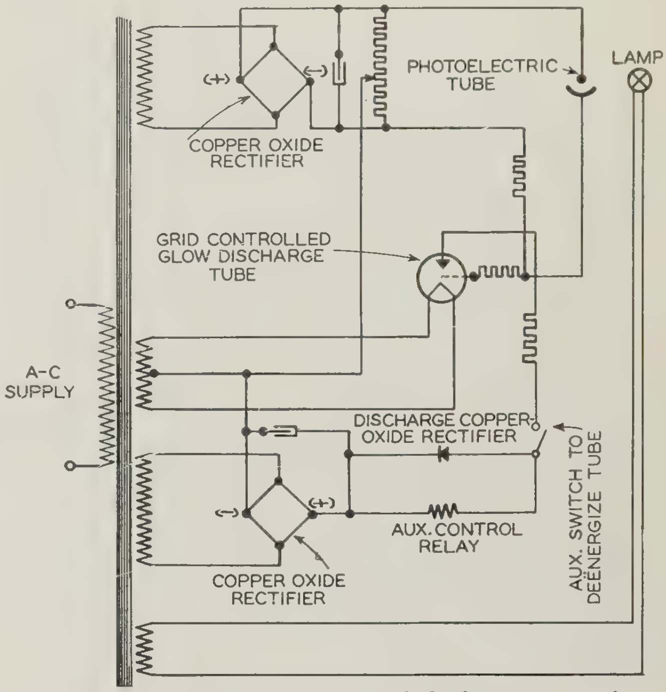


Fig. 3. Schematic diagram of lock-in type of photo-electric controller

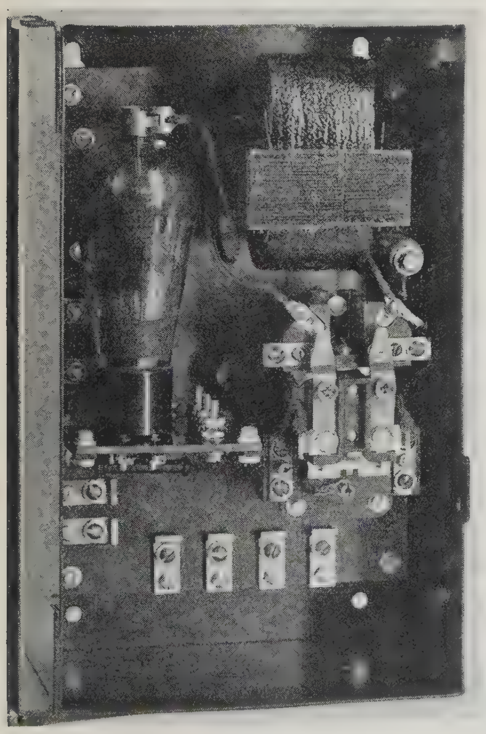


Fig. 2. Front view of photo-electric controller

Photo-Electric Inspection. Numerous applications of photo-electric equipment for inspection purposes have been made. In many applications the time available for inspection is so short that self-locking photo-electric equipment as shown in figure 3 and figure 4 must be used.

An interesting application of the equipment shown in figure 4 was made in connection with a labeling machine for nail polish bottles. The bottles were fed continually through the labeling machine at a rate of one per second. Each shade of nail polish used a different type label. The labels were supplied by the printer in stacks of one thousand, and although extreme care was exercised by the printer in

supplying the correct labels, there would occasionally be several unmatched labels in each stack. This condition was of course highly undesirable, and an investigation of the problem indicated that it would be less expensive to sort the labels at the labeling machine than to have the printer perform the sorting operation.

The labeling operation was performed by having the bottles travel intermittently on a conveyor past the stack of labels mounted in the label magazine, which would move horizontally forward toward the bottle when the bottle was stationary. The side of the bottle had previously been covered with glue, and a label would therefore stick to the bottle so that when the label magazine moved away from the bottle the label would be detached from the magazine, and would remain glued to the bottle. When the label magazine was moved away from the bottle, the magazine would remain stationary during 0.3 second and during this time the finished bottle would move away from the labeling position and a new bottle would move into position. During this 0.3 second the scanner shown in figure 5 was moved down in front of the label magazine in order to inspect the label which was next to be attached to a bottle. In order to be able to do this inspection, a black spot had been printed on the rear side of the labels. The position of this black spot was different for each of the 8 different labels, corresponding to the 8 different shades of nail polish. When the photo-electric scanner had been moved down to the correct position

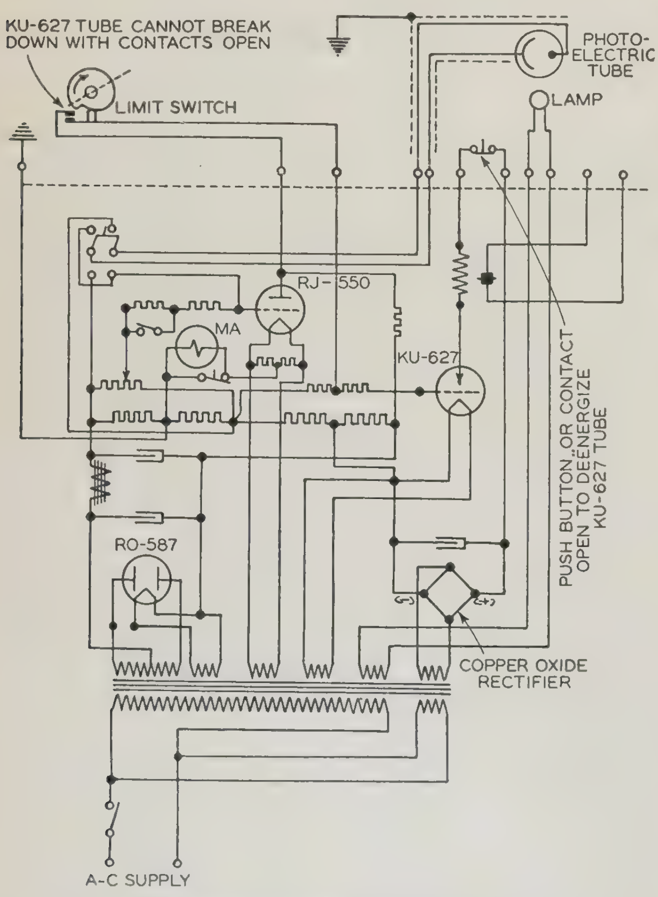


Fig. 4. Schematic diagram of lock-in type photo-electric controller with amplifier tube

the beam of light would fall on the black spot on the label if the correct label was in the label magazine, and the photo-electric controller would not operate, because no light was reflected from the black spot to the photo-electric tube. If, however, the label should be upside down in the label magazine, or if an incorrect label was in the magazine, the light beam would scan the white rear side of the label, and part of the light would be reflected to the photo-electric tube which would cause the photo-electric controller to operate and give a signal so that the girl operating the machine could inspect the bottles and remove the bottle with the incorrect label.

Paper Cutter Control. In figure 6 is shown a special photo-electric controller which is designed to supply, normally, direct current to a solenoid or a relay, and to cause the current through this solenoid or relay to be interrupted during a definite time interval following a momentary decrease in the intensity of illumination on a photo-electric tube. This controller is particularly suited to intermittent type paper cutter machines, when it is desirable to use a spot printed on the paper as a means for deënergizing a clutch between the driving mechanism and the feed rolls, and thus stop the paper while the cutting operation is performed. The type *RJ*-550 tube

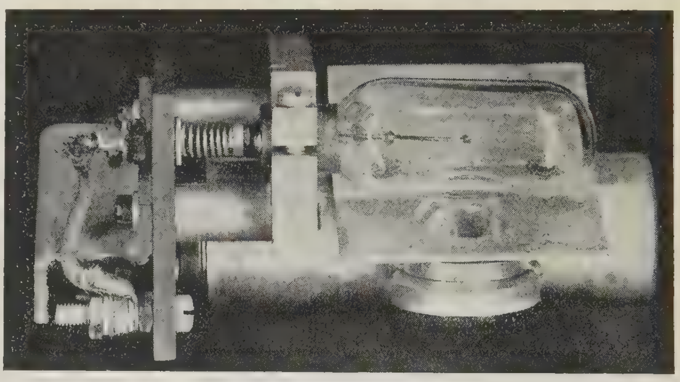


Fig. 5. Scanner for labeling machine

anode circuit is connected to control the grid voltage of the type *KU*-627 tube so that the *KU*-627 tube will break down when the anode current of the type *RJ*-550 tube decreases. A potentiometer and a resistor are connected in series with the anode circuit of the type *KU*-627 tube, and the voltage drop is applied to the grid of the type *RJ*-563 tubes. Before breakdown of the *KU*-627 tube, the *RJ*-563 grid voltage is zero, and the current through the *RJ*-563 tubes, and consequently the solenoid current, is maximum. When the *KU*-627 tube does break down, the condenser in parallel with the tube discharges through the *KU*-627 tube until the voltage across the *KU*-627 tube is approximately 15 volts, which is equal to the arc drop across the tube. At this moment the discharge current is interrupted, and the condenser will start to charge up through the resistor. At the instant of breakdown of the type *KU*-627 tube, therefore, a high negative bias is applied on the grid of the type *RJ*-563 tubes, and the solenoid current becomes zero. As the condenser

becomes charged the negative voltage on the grid of the type *RJ*-563 tube decreases, and after a definite time interval, dependent upon the adjustment of the time delay potentiometer, the *RJ*-563 tube anode current, i. e., the solenoid current, will again reach its maximum value.

Elevator Control. Photo-electric equipment has been extensively used in elevator service to protect

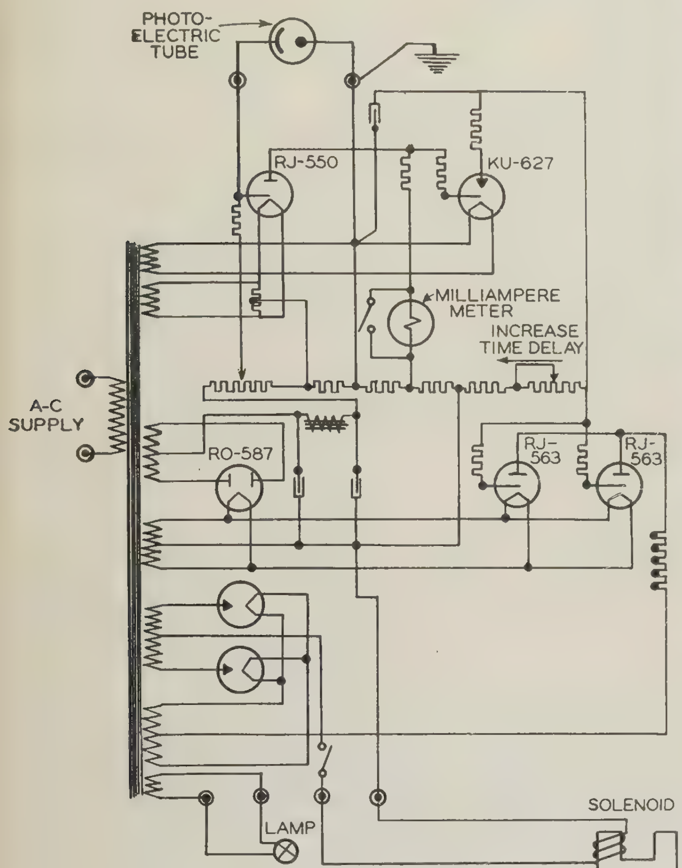


Fig. 6. Schematic diagram of lock-in type photo-electric controller with time delay

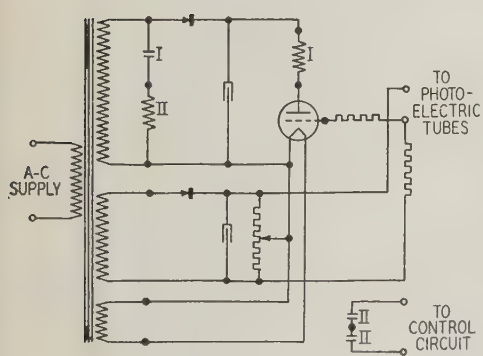


Fig. 7. Schematic diagram of protective door control device

passengers against closing doors, and for elevator leveling control. The protective door control device shown in figure 7 consists of 2 photo-electric tubes, amplifying equipment, and 2 light sources which project 2 beams of light across the door opening to the 2 photo-electric tubes. Obstructing either beam of light prevents the door from closing, or if they are already in motion, immediately causes them to reopen

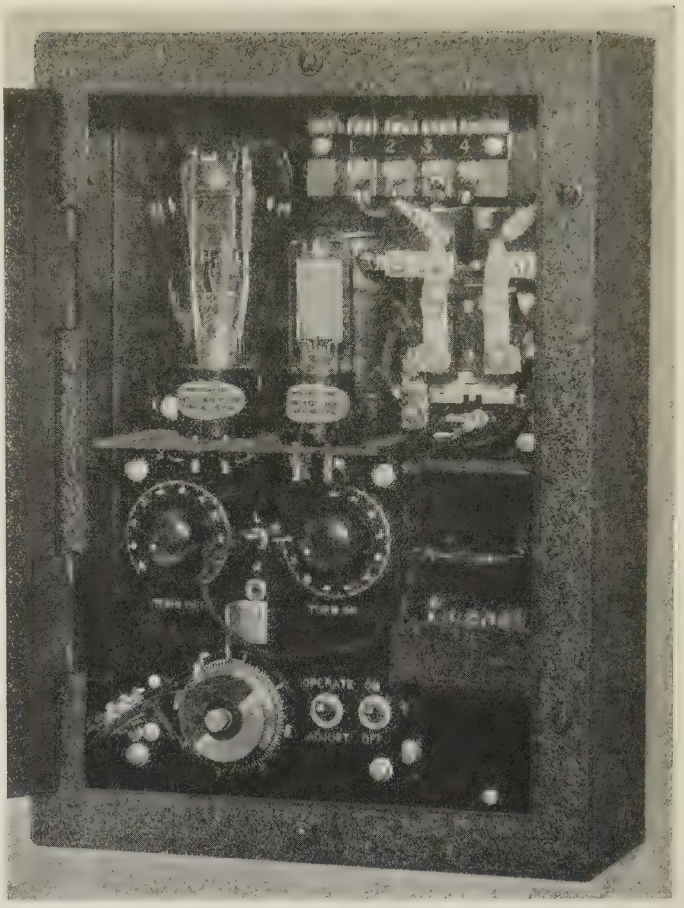


Fig. 8. Front view of device for turning lights on or off, depending on daylight intensity

Lighting Control. The photo-electric device as shown in figure 8, with diagram in figure 9, operates to turn electric lights on or off when daylight decreases or increases in intensity. The applications for this unit are many and they vary from eliminating twilight zone lighting, to lending a maximum of advertising value to illuminated signs and show-windows that no manual operation ever succeeded in reaching. Some of the places where this device is applied to turn artificial light on and off, without any supervision are as follows: Offices, industrial plants, show windows, schools, signs, floodlighting installations, street lighting, navigation lights, and airway and airport lighting.

The operation of this photo-electric light control device depends upon the variation in current through the photo-electric tube caused by variations in light intensity on the tube. This varying current is amplified in an amplifier tube and energizes a primary relay. The primary relay energizes the main contactor. Interposed between the relay and contactor is a time delay button functioning on both opening and closing to give several seconds time delay. The time delay avoids operation by walking in front of the unit or by lightning flashes at night.

If either the photo-electric tube or amplifier tube fails from a normal cause, the device will leave the light turned on, and in this way insure illumination

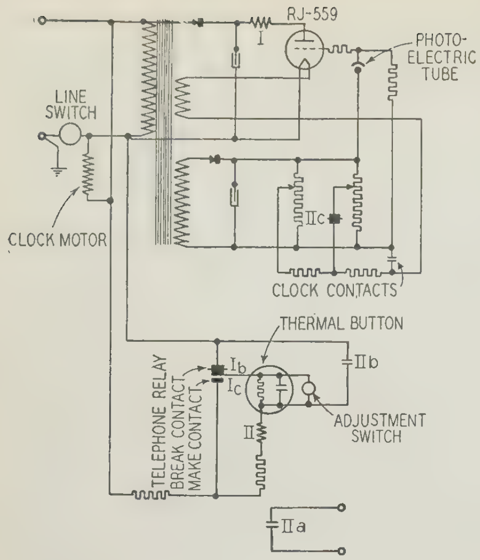


Fig. 9. Schematic diagram of device shown in figure 8

during periods of darkness and indicate failure in the daytime. Adjustment is provided by 2 convenient dials. One dial controls the light intensity at which the device turns on the light. The other dial controls the light intensity at which the device turns off the light.

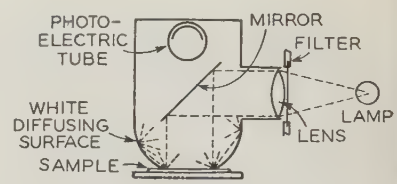
Color Matcher. The photo-electric color matcher is one of the new electronic tools which help to eliminate the error caused by human judgment in various industrial processes and operations. The color matcher contains a matching circuit consisting of a photo-electric tube, a low-grid-current amplifier tube, a coupling circuit, a sensitivity control, and 3 color screens. With the amplifier is a meter with a calibrated dial giving a quantitative indication of the amount of light the sample reflects. A rectifier tube and a filter provide anode and grid voltage for the matching circuit. A tungsten lamp furnishes the source of illumination. Other equipment includes a transformer and a voltage regulator. The latter is required to secure the close regulation on commercial circuits required because of the extreme sensitivity of the matcher. The color screens permit comparison to be made between a sample and a standard in each of 3 bands of the spectrum, blue, green, and red. The arrangement of the matcher is shown in figure 10. Light from a Mazda lamp passes through 1 of the 3 color filters, is concentrated into parallel rays by a lens system, and is reflected by a mirror onto the sample. This light reflected by the sample in turn reaches the photo-electric tube. The meter gives a quantitative indication of the amount of light of that particular color the sample reflects by reading the anode current in the amplifier tube.

Transparency Meter. A simple and accurate means of measuring the transparency of flat materials is obtained by the use of a photo-voltaic device in combination with a light source, a meter for indicating the transparency, and a potentiometer for sensitivity adjustment. The photo-voltaic device generates an amount of current proportional to the amount of light striking it, and therefore a meter reading can be obtained which can be expressed directly in percentage transparency, this term being used to designate the amount of light emerging from a material in comparison to the amount of impinging on it.

Temperature Control. Considerable work has been done during the last few years to adapt photo-electric equipment to pyrometric control of temperatures. In figure 11 is shown a diagram of equipment designed for heater control, which operates from the light emitted from a piece of hot metal which is being heated electrically. The light from the metal falls on a photo-electric tube which in turn actuates a grid-glow tube directly. The grid glow tube operates a contactor. The equipment is designed for automatically shutting off the power supply to a heater. Since the amount of light emitted is dependent upon the temperature of the metal, the device can be arranged to trip the power supply at a predetermined temperature. Provisions are included in the equipment to lock out the power circuit immediately after the metal reaches the proper temperature and the operation is reinitiated only when the operator has put in a new piece of metal and depressed a starting button manually.

Concentration Control. There are numerous possibilities for application of photo-electric equipment

Fig. 10. Schematic arrangement of color matcher



in electrochemical industries and in other process industries. In order to keep electrochemical processes functioning within tolerable limits, it has been necessary, in many cases, to resort to close supervision by chemists, who at definite intervals sample the liquids to determine their concentration. This procedure is expensive, and the accuracy of control obtained depends to a large extent upon the physical condition and fatigue of the analyst. To eliminate

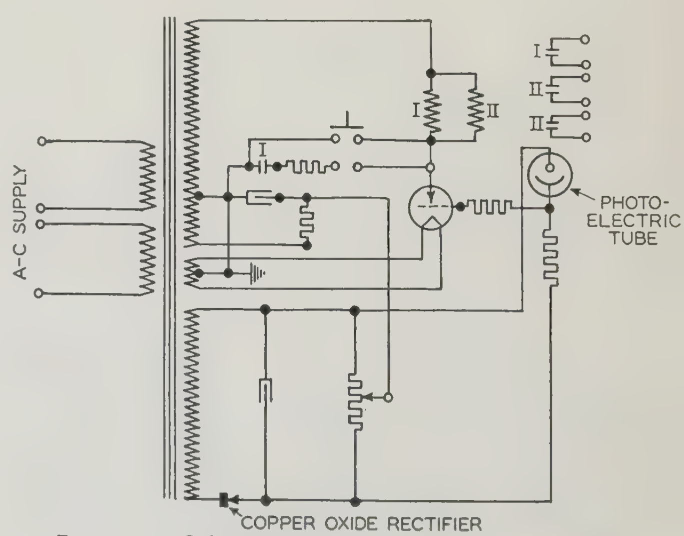


Fig. 11. Schematic diagram of heater control

the human element in various types of process control, a concentration indicator has been developed. This apparatus is at the present time available only as an indicator, but the design is arranged so that with minor modifications the equipment may be used also as a regulator.

The diagram of the concentration indicator is shown in figure 12, and the principle of operation is apparent from this diagram. A standard sample is placed on one side of a light chamber, while the material or liquid to be inspected is arranged to pass

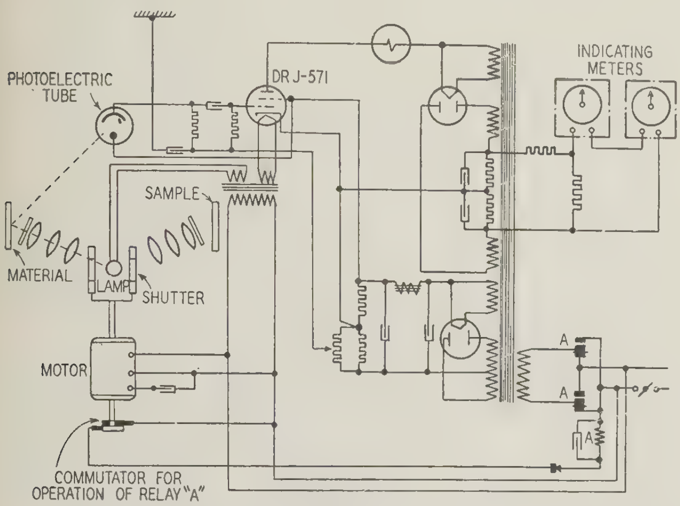


Fig. 12. Schematic diagram of concentration indicator

continuously by the other side of the light chamber. By means of a shutter operated by a synchronous motor, a beam of light is thrown alternately to the standard sample and to the material to be inspected, and is then reflected to the photo-electric tube. If the color of the sample matches with the color of the material, the photo-electric tube will obtain the

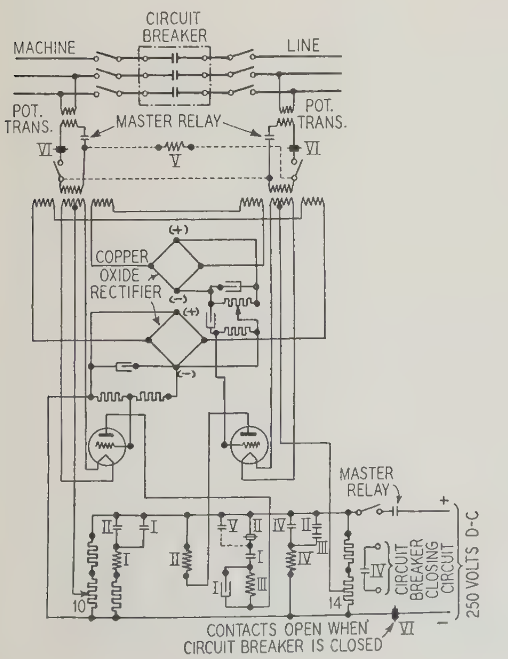


Fig. 13. Schematic diagram of synchronizing relay

same illumination during each half of the a-c voltage wave, and the output of the type *RJ*-571 screen grid amplifier tube will be such that the indicating meter will read zero. If the colors do not match, the photoelectric tube illumination will be greater during one half of the cycle than during the other, and the indicating meter will then deflect to one side or the other depending upon whether the color of the material is too dark to too light.

II. Electronic Relays

Comparatively little work has been done on the practical development of electronic relays for industrial and central station control applications. The characteristic of the various types of electronic tubes, and especially the characteristic of the grid controlled glow discharge tube is admirably suited to relay applications, and general adoption of electronic tubes in the relay art is bound to occur ultimately.

Synchronizing Relay. A few electronic relays are now commercially available and several installations of these relays have been made. A particularly interesting application is the electronic synchronizing relay which was developed and placed on the market in 1930. This relay is an example of an electronic device which due to superior operating characteristic has superseded the electromagnetic devices previously used in the same applications. The synchronizing relay shown in figure 13 was designed primarily as a low energy device to make synchronizing equipment available which could be operated from condenser bushing potential devices. The synchronizing relay which has a "proportional advance" characteristic will energize the circuit breaker closing relay a definite time ahead of the instant of phase coincidence, corresponding to the breaker closing time, so that, regardless of the frequency difference, the circuit breaker contacts will always close so as to give minimum equalizing current at the paralleling moment.

Time Delay Relays. Electronic time delay relays have been extensively used, both in circuit connections with other electronic equipment, and as separate electronic timers. The advantages of electronic time delay relays as compared with mechanical and

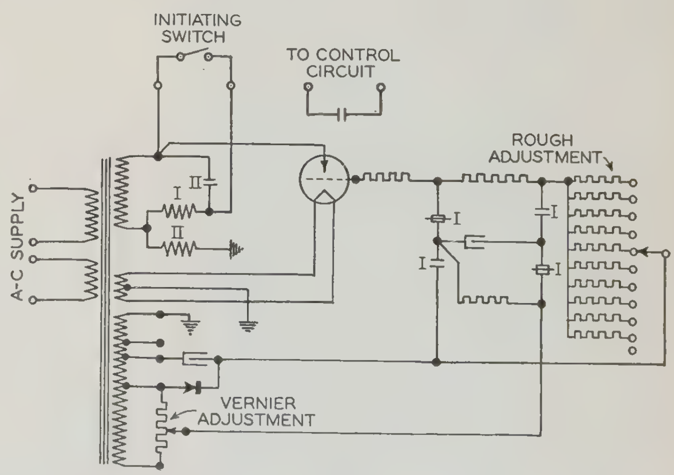


Fig. 14. Schematic diagram of electronic timer

electromagnetic relays, are the accuracy, the wide range and ease of time delay adjustment, and the low maintenance.

An electronic timer as shown in figure 14 was developed as an electronic spot welding control, but due to its reliability, simplicity, and ease of adjustment, the relay has found a wide field of application in industrial installations where definite time intervals are required. The equipment is arranged to stay closed a definite interval of time, which may be adjusted from 0.1 second to 40 seconds. The timing is practically independent of line voltage variations and is not affected by ambient temperature. The timer contains a relay II for external connections, and a relay I for changing internal connections. A grid controlled glow discharge tube in connection with a condenser discharge circuit is used for timing purposes. When both relays I and II are open, the tube does not pass current, but a condenser is being charged to a voltage determined by the position of one of the control potentiometers. When the external initiating switch is closed, relay I pulls in, reversing the condenser connections, and causing the tube to pass current to relay II. Relay II will therefore operate, and remain closed a definite time while the condenser is being discharged, until the condenser voltage has reached the value at which the tube stops passing current.

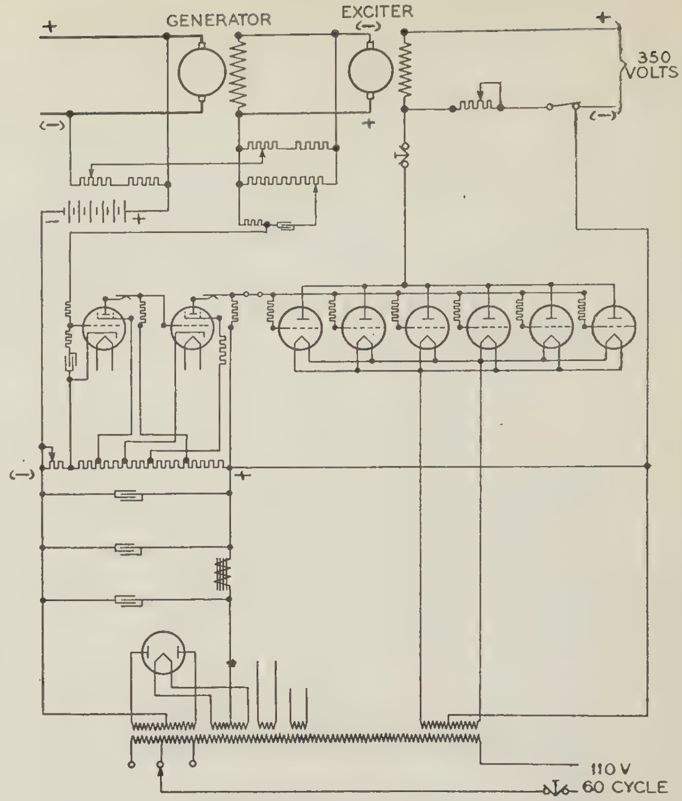


Fig. 17. Schematic diagram of voltage regulator for d-c generators

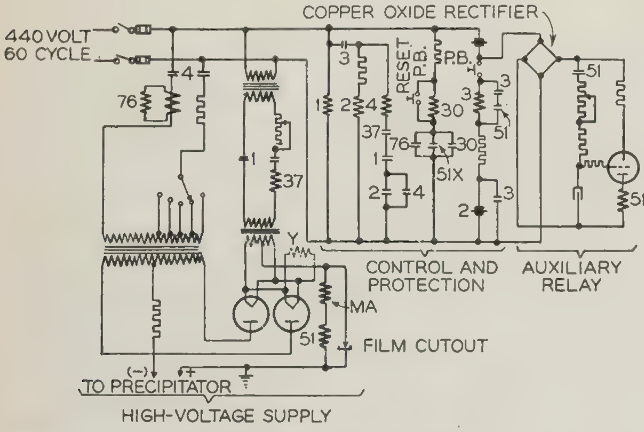


Fig. 15 (above). Schematic diagram of precipitation equipment

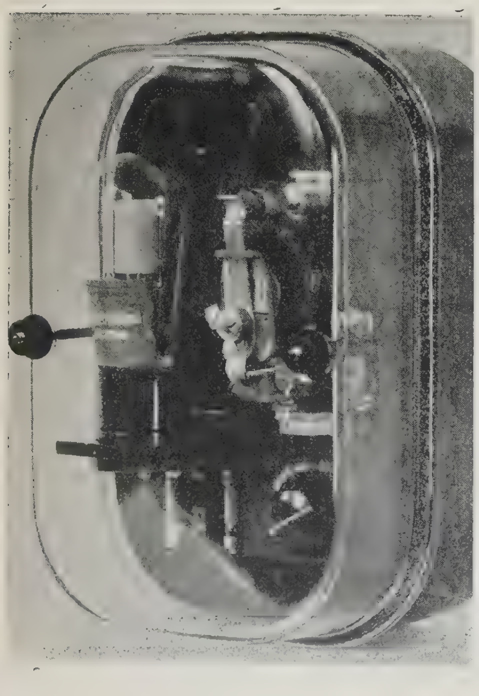


Fig. 16. Integrating time delay relay

Precipitation Control. A special design of integrating time delay relay using a cold-cathode grid-controlled glow-discharge tube has been used in connection with precipitation equipment to protect the equipment against prolonged short-circuit conditions. The schematic diagram for precipitation equipment applying this relay is shown in figure 15. A photograph of the relay is shown in figure 16. The relay is an assembly consisting of a cold-cathode grid-controlled glow-discharge tube, a small condenser, associated resistors, and an auxiliary relay designated as $51X$. This protective equipment operates in the following manner. One set of contacts of the overload relay 51 deënergizes the master relay 3 while the other set of contacts in the grid circuit of the relay energizes the condenser-resistor circuit, applying a certain potential to the condenser. This, however, is only a momentary contact, because the opening of the plate supply contactor 4 immediately removes the main current and resets the overload relay. The potential on the condenser at this time is insufficient to cause discharge of the grid controlled glow discharge tube, but it does not leak off for quite a long while. After a short interval the plate supply contactor is reclosed again, and if the short-circuit condition still remains, the same procedure is repeated, but this time the charge on the condenser is increased. The periodic opening and closing of the circuit continues until the charge on the condenser has reached the value at which the anode-cathode discharge of

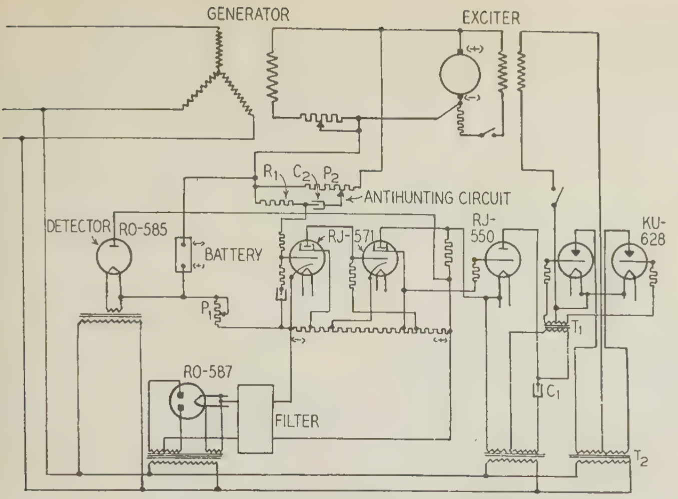


Fig. 18. Schematic diagram of voltage regulator for a-c generators

the grid controlled glow discharge tube will take place thus energizing the auxiliary relay 51*X*. The contacts of the auxiliary relay energize lockout relay 30, which in turn seals its own circuit, and by means of one of its contacts keeps the circuit of the plate-supply contactor 4 deënergized. The equipment is thus held out of service until relay 30 is reset by hand.

III. Electronic Regulators

During the last several years a number of applications have appeared in various industries, where the energy available to operate regulating equipment was of such low magnitude that application of the conventional type electromechanical regulators could not be considered. Most electromechanical regulators require approximately 100 voltamperes for operation, while electronic regulators can be designed to operate from considerably less than one microwatt. Due to this reduction in control energy requirements, brought about by the electronic tube, the entire art of automatic regulator design has been modified. While previously the only practical indicating element available to the regulator designer was the electromagnetic solenoid, a wide variety of indicating circuits varying from photo-electric to resistance or capacity controlled devices, are now at the disposal of the regulator engineer. In addition to this greater choice of indicating circuits, electronic tubes offer possibilities for design of regulators having extremely high sensitivity and a quick response characteristic. The quick response characteristic is obtained through the elimination of friction and inertia inherent with all electromechanical regulators, and through the development of special electronic antihunting circuits which permit powerful corrective regulator action, without any danger of overshooting or hunting.

D-C Voltage Regulator. An electronic voltage regulator for d-c generators as shown in figure 17 has been used in applications where high sensitivity and quick response action were of importance. In most industrial applications of d-c voltage regulators, a sensitivity of one per cent is entirely satisfactory and this sensitivity can be obtained with standard electromechanical voltage regulators. There are, however, applications where a sensitivity of 0.1 per cent is required, and for such applications the electronic type voltage regulator is particularly suited.

Speed Regulator. The d-c type voltage regulator has been used as a speed regulator for single motor paper machine drives. In applications of this type the problem of regulation becomes rather difficult if the equipment is designed to cover a wide speed range of, for example, 12 to 1. The reason for this is that the characteristic of the drive is different at one end of the speed range than at the other end. If a mechanical type of regulator is used, it is often found that if the equipment is adjusted for one speed, it may become unstable at the other end of the speed range. The inherent characteristic of the electronic regulator is such that sufficient antihunting action is always available, and it is therefore possible to stabilize the regulator at any point within the operating range of the equipment. In applying the electronic voltage regulator as a speed regulator, a pilot generator is coupled to the motor, and the voltage of this pilot generator is arranged to act on the regulator so that if the pilot generator voltage increases, the armature voltage of the generator which is supplying the power for the motor will be decreased, and thus the speed of the motor will be maintained at a constant value.

A-C Voltage Regulators. Various types of a-c electronic regulators have been available for a number of years, and the operating results obtained with these devices have been highly satisfactory. It may therefore be expected that in the future the electronic regulator for a-c generators will be generally accepted in the industrial and central station field. One of these a-c voltage regulators as shown in figure 18 was developed for lamp testing applications where an extremely high sensitivity was needed. Operation of this regulator during several months indicates that a sensitivity of 0.1 per cent was consistently obtained. For the average industrial applications such a high sensitivity is not needed and for such applications a simplified electronic regulator which uses no battery, and which employs only 1 control tube and 2 power tubes has been developed.

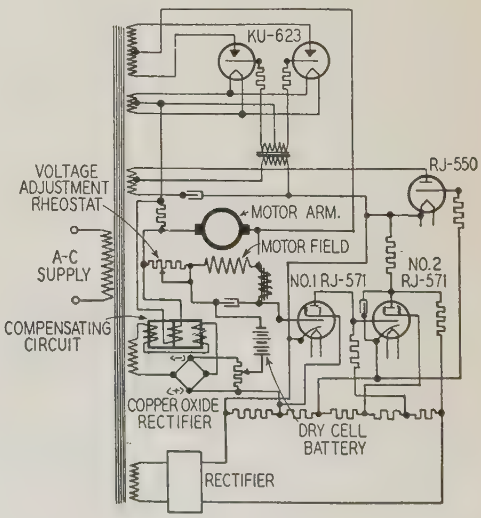


Fig. 19. Schematic diagram of voltage controlled rectifier for motor operation

Motor Control. Considerable interest has been shown in equipment for the control of d-c motors operated from an a-c source, and an electronic device has been developed which makes it possible to maintain a constant rectified d-c voltage supplied by grid controlled glow discharge tubes. This is accomplished by a voltage regulator which maintains the d-c voltage at a constant value regardless of variations in the a-c supply, as shown in figure 19. By means of a compensating circuit the regulated voltage may be given a compound characteristic so that the voltage will increase with increasing load.

Coating Machine Regulator. Various industrial regulators have been developed for special applications and a few of these applications will be referred to, to indicate the possibilities of, and the wide scope of industrial electronic regulators.

A regulator has been installed at a paper mill to control the speed of a motor feeding paper from a coating machine to a drying oven. The paper would form a loop between the coater and the dryer, and the regulating problem was to control the length of this loop so as to prevent the paper from tearing, or to prevent the loop from becoming so long that the paper would drag on the floor. Since the paper was wet at the point where the loop was formed, it would not have been practical to install any mechanical device to control the speed of the motor feeding the paper from the coater to the drying oven. A photoelectric relay in connection with an electronic type vibrating regulator was arranged as shown in figure 20, to operate in the mortor field and in this manner control the rate of paper feed.

Register Regulator. During the last several years considerable interest has been shown the application of electronic equipment in the paper finishing industry, to control the cutting of paper so as to keep the cut itself in register with characters or designs previously printed on the paper. The control of the position of the paper relative to the cutter is obtained by printing a spot on the paper so that the spot has a fixed location in relation to the design of the paper. By means of a beam of light reflected from this spot to a photo-electric tube, and by means of a selector switch geared to the cutter, an indication of the position of the paper relative to the cutter is given. Control relays as shown in figure 21 are arranged to correct the paper speed through a mechanical differential in order to maintain register between the cutter and the paper. Figure 22 shows the mechanical arrangement of a bag machine equipped for automatic register control. A unique feature of this register regulator is the compensated scanner. This scanner employs 2 photo-electric tubes. One is used as the pick-up tube, the other is used as a balancing tube. These photo-electric tubes are connected in a bridge circuit so that the equipment will remain in calibration if the a-c supply voltage should change, or if the color or finish of the paper should change.

Frequency Regulators. Since there is only a need for frequency regulators of the rheostatic type, there has been no particular incentive to develop an elec-

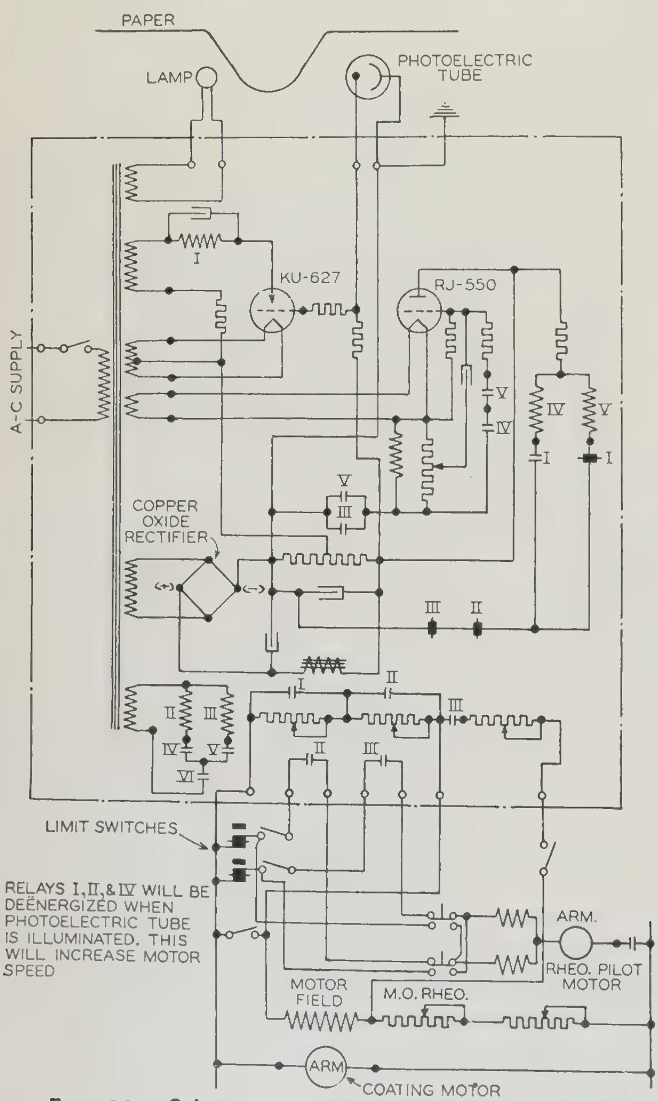


Fig. 20. Schematic diagram of coating machine regulator

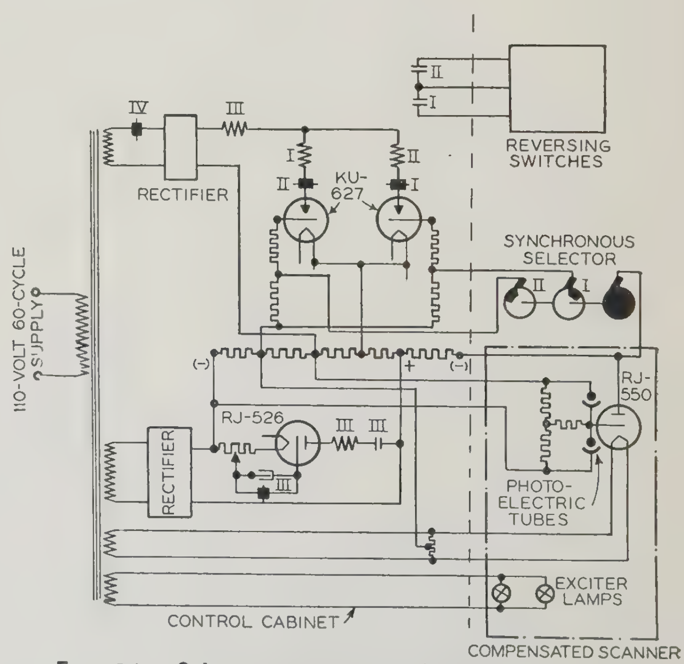
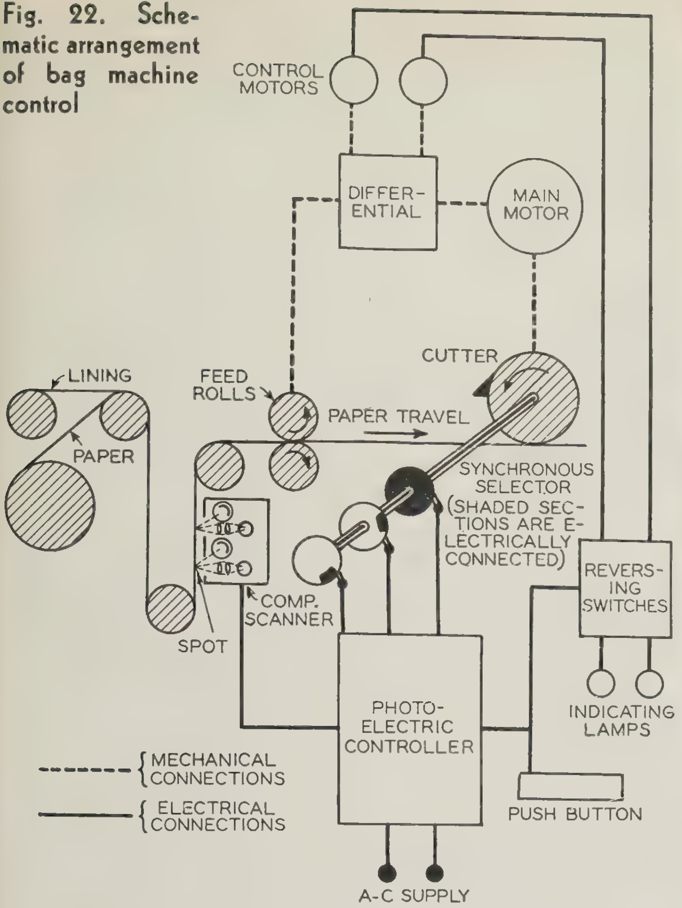


Fig. 21. Schematic diagram of register regulator with compensated scanner

Fig. 22. Schematic arrangement of bag machine control



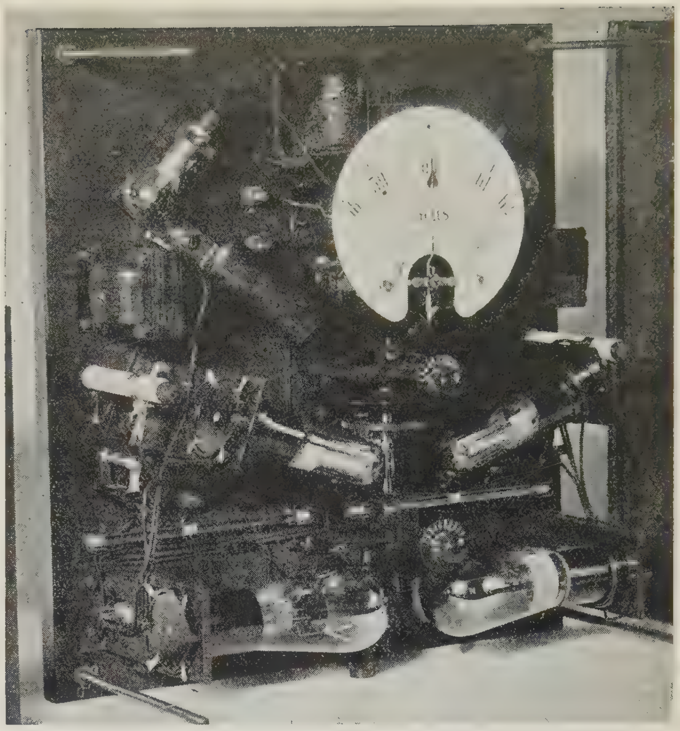


Fig. 23. Photo-electric frequency regulator

tronic frequency regulator. Experiments with electronic frequency regulators however have been made in various laboratories, and numerous patents have been issued covering electronic frequency control equipment. The majority of these experimental regulators employ tuned frequency circuits in various combinations with electronic tubes.

A photo-electric frequency regulator as shown in figure 23 has been used in a few installations. This device is not entirely electronic inasmuch as an electromagnetic indicating instrument is used in connection with photo-electric amplifying means. This regulator may be used for other purposes than frequency regulation and because the equipment embodies some novel regulator design features a description of the device may be of interest. A dynamometer type resonant circuit meter is used as the frequency indicating element. A small mirror is mounted on the shaft of the moving element of this meter and 2 light beams are projected to this mirror, and then reflected from the mirror to 2 photo-electric tubes. When the meter pointer is in the center position, both photo-electric tubes are dark, but for the slightest movement of the pointer, one of the photo-electric tubes will be illuminated, and the grid controlled glow discharge tube controlled by the photo-electric tube will break down and operate a relay, which picks up another relay controlling the speed changer motor. Antihunting is incorporated in this regulator by means of a rotating disc which intercepts the light beams. This disc which makes one revolution in 2 seconds permits a time of photo-electric tube illumination which is proportional to the deflection of the meter. The time of governor correction therefore will be approximately proportional to the error in regulated frequency.

IV. Welding Timer for Seam Welding

The process of seam welding consists of discharging an enormous current at low voltage through 2 or more pieces of metal to form a spot. The pieces of metal being joined together are passed between rollers of low resistance material which serves to conduct the high current into the metal being welded. The 2 pieces of metal being welded are forced together by mechanical pressure on the rollers so as to unite the 2 pieces after they have been heated to fusing temperature. This discharging of current lasts for only a few cycles and is then stopped until the material has moved along slightly, after which power is again applied to the welding machine. Seam welding is therefore merely a modification of the familiar spot welding so performed that the spots overlap each other and thus form a continuous seam which is liquid and gas tight.

A welding timer which depends for its operation principally upon electronic tubes, has been developed to meet the requirements of seam welding control where timing of the order of a few cycles on and a few cycles off is required. This welding timer has been described in detail in a paper "A New Timer for Precision Welding" by R. N. Stoddard, appearing in the October 1934 issue of Electrical Engineering, pages 1366–70. It permits very high welding speeds with highly accurate and consistent results. Typical applications include the welding of light gauge materials where ordinary methods fail to produce uniform results.

Dielectric Strength of Mineral Oils

The correlation of the pressure and temperature effects in determining the dielectric strength of mineral insulating oils is considered in this paper. The effect which gas dissolved in the oil has on the dielectric strength of the oil is shown by experimental results of tests on the effect of temperature and pressure. Based upon these results, simple formulas for expressing the dielectric strength of oil are obtained.

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IT has been suggested[1,2] that for the proper understanding of those factors which determine the dielectric strength of liquid insulation under varying conditions of test, consideration must be given to the presence or absence of dissolved gases. The solubility of air and its constituent gases in mineral insulating oil has been described. The effects of such solubility have been traced by noting the dielectric response of the liquid under varying experimental conditions. Based upon such phenomena, an orderly arrangement of dielectric behavior for liquid insulation is easily obtained if the materials are classified into 2 main groups which have been designated as the "pure" and the "impure" classes of insulating liquids.

It is beyond the scope of the present paper to elaborate upon this classification. Reference should be made to the previous articles. The object of this paper is to demonstrate the application of the principles of the "impure" liquid classification. In the application of these principles, a correlation of the pressure and temperature effects in determining the dielectric strength of mineral insulating oils is obtained.

The "impure" liquid dielectric has been described as including all insulating liquids which contain dissolved gas. A de-gassed liquid, one free from all traces of dissolved air or other gases, is classified as a "pure" liquid dielectric. The presence of secondary impurities such as water and suspended particles, although important, is not necessarily involved in this classification. Such materials are referred to as "contaminants" and may be present in either class of liquids without affecting the general classification, although the absolute dielectric strength value may be changed as a result of the presence of such "contaminants."

A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted Oct. 15, 1934; released for publication Nov. 7, 1934.

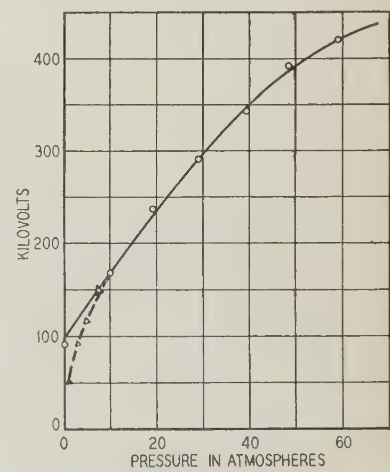
1. For all numbered references see list at end of paper.

The Effect of Pressure and Temperature

The dielectric strength of "impure" mineral insulating oils reflects changes in the applied gas pressure and the testing temperature. The dielectric strength changes with the applied gas pressure as illustrated in figure 1. Although the data of figure 1 are based upon the behavior of a transformer oil of low viscosity, experimental evidence has been obtained that irrespective of the type of mineral oil (and even irrespective of the chemical type of the "impure" liquid), the effect of gas pressure is of the same order, an increasing dielectric strength resulting with increased gas pressure applied above a certain critical value for which the dielectric strength of the "impure" insulating liquid is at a minimum. This critical pressure is invariably of the order of a few hundred microns of mercury.

Fig. 1. The effect of pressure on the dielectric strength of transformer oil

Experimental data (circles) from Kock (reference 7)



With changing temperature of test an apparent contradiction in behavior is obtained. With light, low viscosity oils of the transformer type, the dielectric strength increases with increasing temperature from 25 degrees centigrade. With heavy, mineral, cylinder oils, the dielectric strength falls as the testing temperature is increased from 25 degrees centigrade, other conditions being unchanged. Figure 2 shows this relation.

The contrasting dielectric behavior of different oils with temperature change and the constant behavior of these oils under pressure change can be correlated with proper consideration of the "relative dissolved air density" existing in the oil under examination. For this interpretation, reference is first made to the recognized dielectric behavior of air.

The Characteristics of Gaseous Breakdown

The mechanism underlying the dielectric breakdown of gases is recognized as involving the phenom-

enon of cumulative ionization resulting from the collision of charged particles under the influence of the applied electric field.[3] As such, the dominating influence involves not only the strength of the field, but also the mean free path of the moving particles. Changes in the gas density, caused either by pressure or temperature variation, directly affect the mean free path with resulting change in the dielectric strength of the gas. The voltage at spark over under carefully controlled experimental conditions varies directly with changes in gas density, increasing with increasing pressure at constant temperature and decreasing with the increasing absolute temperature at constant pressure in accordance with the usual gas laws, the spark length remaining constant.[4,5] This linear relation (Paschen's law) holds true between widely varying limits.

The effect of changing density on the dielectric strength of air may be illustrated by reference to the change in dielectric strength with temperature. Accepting the relative air density as equal to unity at 25 degrees centigrade, 760 millimeters of mercury pressure, application of the gas laws shows the relative air density at 0 degree centigrade to be 1.091 and at 100 degrees centigrade to be 0.801. Applying Paschen's law without consideration of kinetic phenomena, the corresponding dielectric strength of air would be 32.5 kilovolts per centimeter and 23.8 kilovolts per centimeter, respectively, accepting the breakdown of air to be 29.8 kilovolts per centimeter at 25 degrees centigrade and 760 millimeters of mercury pressure. Over a temperature range from 0 degree to 100 degrees centigrade, the dielectric strength changes, therefore, 0.087 kilovolts per centimeter per degree centigrade. In terms of the breakdown of air (29.8 kilovolts per centimeter at 25 degrees centigrade, 760 millimeters of pressure)

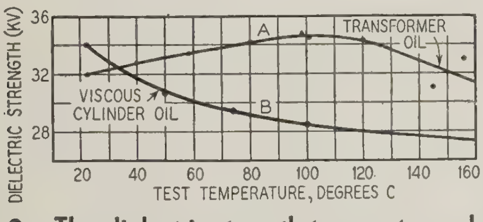


Fig. 2. The dielectric strength-temperature relation for mineral oils tested at atmospheric pressure

the change in dielectric strength is 0.27 per cent per degree centigrade, a value in agreement with the experimental results already reported by Ryan[6] and Whitehead.[8]

Relative Gas Density as Applied to "Impure" Insulating Liquids

Air solubility in mineral oil at 25 degrees centigrade, 760 millimeters of pressure depends upon the physical and chemical characteristics of the oil itself, being greatest with the low viscosity oils of the transformer type. The following tabulation serves to show the change in air solubility at 25 degrees centigrade in selected, refined fractions from the same parent crude oil stock of Texas origin. In this tabulation the volume of the gas is reduced to 25 degrees centigrade, 760 millimeters of pressure and is expressed in per cent of the total oil volume.

Low viscosity fraction (55 seconds at 37.8 degrees centigrade)—10 per cent

Medium viscosity fraction (100 seconds at 37.8 degrees centigrade)—8.3 per cent

High viscosity fraction (1,600 seconds at 37.8 degrees centigrade)—6.5 per cent

The dielectric strength at 25 degrees centigrade of these mineral oil fractions is independent of the stated variations in oil-dissolved air, all oil fractions having a dielectric strength ranging from 30 to 40 kilovolts when carefully tested between 1 inch diameter brass disk electrodes spaced 0.100 inch apart. The dielectric strength is affected, however, as the oil-dissolved gas content, characteristic of the oil under standard conditions (25 degrees centigrade, 760 millimeters) is varied. Stated in general terms, the absolute value of liquid-dissolved gas is not of major importance in determining the dielectric strength of the insulating liquid. It is the relative liquid-dissolved gas density which is the determining influence in affecting the electrical breakdown value. The effect is analogous to the effect of the relative air density in influencing the dielectric strength of air already referred to.

Definition of Relative Liquid-Dissolved Gas Density

The density of matter is usually expressed as the mass per unit volume, measured under accepted standard conditions. In discussing the amount of dissolved gas present in the "impure" liquid dielectric, expression has been made in terms of per cent gas per volume of liquid, the volume of the gas being reduced to 25 degrees centigrade and 760 millimeters of pressure, called standard or normal conditions. Since the gas volumes measured have all been reduced to a selected "standard" condition of temperature and pressure, defining as unity the liquid-dis-

Fig. 3. The effect of temperature on the solubility of air in mineral transformer oil

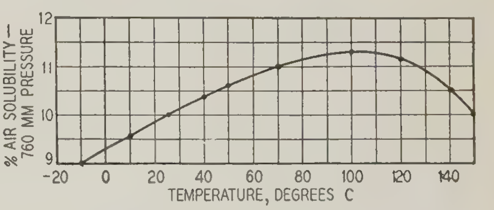
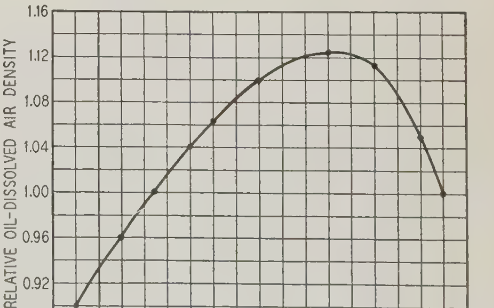


Fig. 4. The relative oil-dissolved air density in mineral transformer oil as a function of temperature



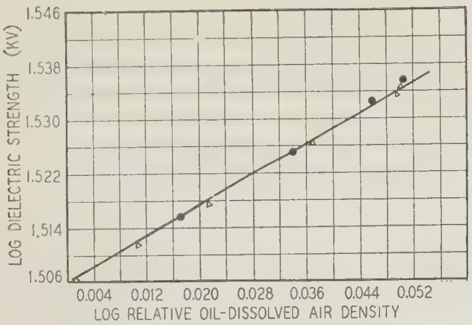
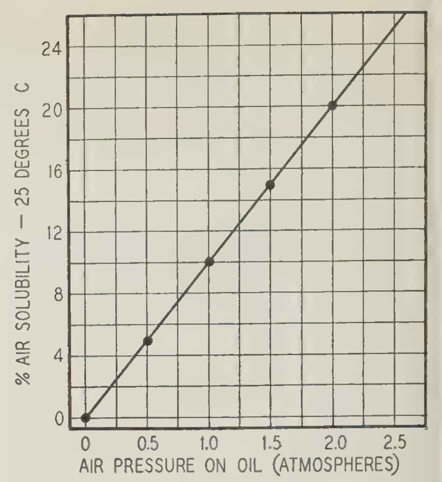


Fig. 5. Showing the logarithmic relation between the relative oil - dissolved air density and the dielectric strength of mineral transformer oil

Dots represent values for tests from room temperature to maximum dielectric strength (approximately 100 degrees centigrade. Triangles represent values for tests from temperature of maximum dielectric strength to 150 degrees centigrade

Fig. 6. The effect of air pressure on the solubility of air in mineral transformer oil, tested at 25 degrees centigrade



solved gas density under such conditions, the relative liquid-dissolved gas density may then be expressed as

$$D = \frac{V^1}{V} \tag{1}$$

where

D = relative liquid-dissolved gas density

V = per cent gas solubility (by volume) in the liquid tested under standard conditions (25 degrees centigrade, 760 millimeters pressure)

V^1 = per cent gas solubility in the liquid (by volume) under the specially selected conditions, the volume of gas having been reduced to 25 degrees centigrade, 760 millimeters pressure

The application of this concept of relative liquid-dissolved gas density is used to correlate the often conflicting effects of temperature and pressure on the dielectric strength of insulating liquids.

The Temperature Effect

Under changing temperature at a constant gas pressure, the gas solubility in a liquid changes. The solubility of air in mineral insulating oil may increase or decrease depending upon the characteristic of the oil under examination. For low viscosity oils of the transformer type, the air solubility increases with increasing temperature. With heavy, viscous oils, an increase in testing temperature produces a decrease in air solubility.

	% Air Solubility	
	at 25°C	at 100°C
Oil *A*—a light oil of the transformer type	10%	11.3%
Oil *B*—a viscous cylinder oil	6.5%	4.8%

The distinctive gas solution characteristics of these 2 types of oils is reflected in their contrasting dielectric behavior with temperature change (figure 2).

Figure 3 shows the air solubility in mineral transformer oil as a function of the testing temperature at a constant pressure of 760 millimeters. The air solubility in the oil reaches a maximum at approximately 100 degrees centigrade. With higher temperatures the gas solubility again decreases. Figure 2 shows that the same oil increases in dielectric strength with temperature, reaching a maximum dielectric strength at 100 degrees centigrade. With further increase in temperature the dielectric strength again falls. The general similarity in the effect of temperature on the oil-dissolved gas content and on the dielectric strength of the oil is not accidental. The dissolved gas content of the oil plays an important rôle in determining its dielectric strength.

Figure 4 shows the relative oil-dissolved air density for mineral transformer oil, calculated from air solubility data which was experimentally determined. The dielectric strength of this same transformer oil is shown in figure 5 to be a logarithmic function of the relative oil-dissolved air density and is expressible as

$$Kv = AD^{0.56} \tag{2}$$

where

Kv = breakdown value at a specially selected temperature, the oil being tested at 760 millimeters between 1 inch diameter disk electrodes spaced 0.100 inch apart

A = dielectric strength of the oil under standard conditions, 25 degrees centigrade, and 760 millimeters

D = relative oil dissolved air density as calculated from equation 1

The application of equation 2 to the problem of the heavy cylinder oil, the dielectric strength-temperature characteristics of which are illustrated in figure 2, allows check on its validity. The dielectric strength of this oil under standard conditions of 25 degrees centigrade, 760 millimeters pressure is given in figure 2 as 33.5 kilovolts. The air solubility in

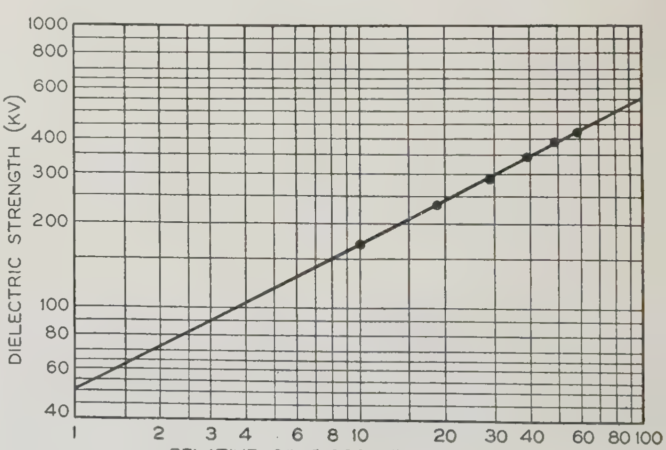


Fig. 7. Showing the logarithmic relation between the dielectric strength and the relative oil-dissolved air density for mineral transformer oil

Based upon figure 1

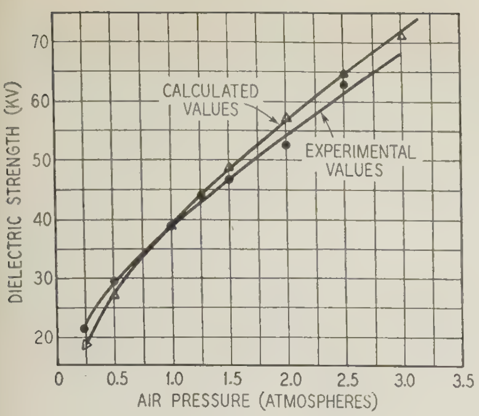


Fig. 8. Showing the relation between the dielectric strength and low values of applied air pressure for mineral transformer oil

this oil under the same conditions has already been stated to be 6.5 per cent. At 100 degrees centigrade, the air solubility is 4.8 per cent. The relative oil-dissolved gas density at 100 degrees centigrade thus becomes 0.73, calculated in accordance with equation 1. Substituting the approximate values in equation 2, it is therefore found that

Kv at 100 degrees centigrade = 28.2 kilovolts

a value in close agreement with the data of figure 2.

The successful application of the concept of relative oil-dissolved air density to the behavior of oils showing either a positive or a negative dielectric strength-temperature relation, or to an oil which first shows a positive and then a negative temperature-dielectric strength relation, clearly substantiates the importance of dissolved gas phenomena in determining the dielectric behavior of mineral insulating oils.

The Pressure Effect

The solubility of air in mineral oil obeys the usual gas solubility laws in that the solubility of the gas increases in a linear relation with the applied gas pressure. Figure 6 shows the relation over the pressure range from 0 to 2 atmospheres, transformer oil of Texas origin being used as the representative insulating liquid. It is possible that the air solubility may not continue to increase indefinitely with the pressure. Experimental confirmation in the extremely high gas pressure ranges is lacking.

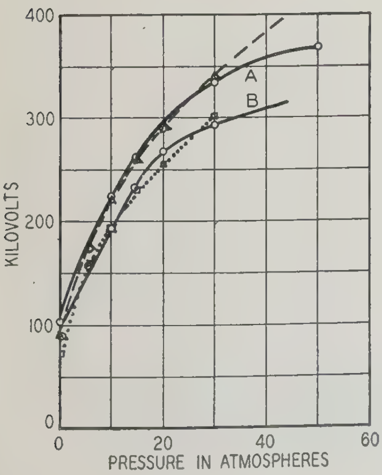


Fig. 9. Showing the relation between applied gas pressure and the dielectric strength of "petroleum" (for 2 different tests, A and B)

Solid lines—Experimental data from Kock (reference 7)

Dotted lines—Calculated data based upon logarithmic relation between the relative oil-dissolved air density and the dielectric strength

In the light of figure 6, figure 1 can now be redrawn showing the dielectric strength of the oil as a function of the relative oil dissolved air density, calculating this factor by the application of equation 1. Figure 7 shows such relationship to be logarithmic. The dielectric strength is expressed as

$$Kv = AD^{0.55} \qquad (3)$$

In figure 1 (based on Kock), it will be observed that the dielectric strength of the oil under zero gas pressure is given as 93 kilovolts. The breakdown for 1 atmosphere air pressure is not given. From the relation (equation 3) this value should be 50 kilovolts. In figure 1, the dotted line relation for the range of pressures from 0 to 10 atmospheres is based upon the application of equation 3.

The relation 3 applies in the range of gas pressures from 1 to 3 atmospheres as shown in figure 8, illustrating the changing dielectric strength of transformer oil, tested at 25 degrees centigrade. The experimental and calculated (equation 3) results are in close agreement.

The logarithmic relation established in equation 3 holds true only for pressures above the "critical gas pressure," below which value the dielectric strength of the oil again increases.

The Analogy Between the Gaseous and Liquid-Dissolved States

An "impure" dielectric liquid under the definition cited is a solution of a gas in a liquid, the usually occurring case being the solution of air in mineral oil. The great advance in physical chemistry of recent years has been in part traceable to the recognition of the far reaching analogy between the gaseous and the dissolved states of matter. The laws governing gaseous behavior are well known. Their application to solution phenomena has contributed valuable knowledge of the nature of solutions, ultimately culminating in the theory of electrolytic dissociation. This advance has been shared by numerous and prominent investigators. It was Newton who pointed out that the dissolved molecules in a solution tend to

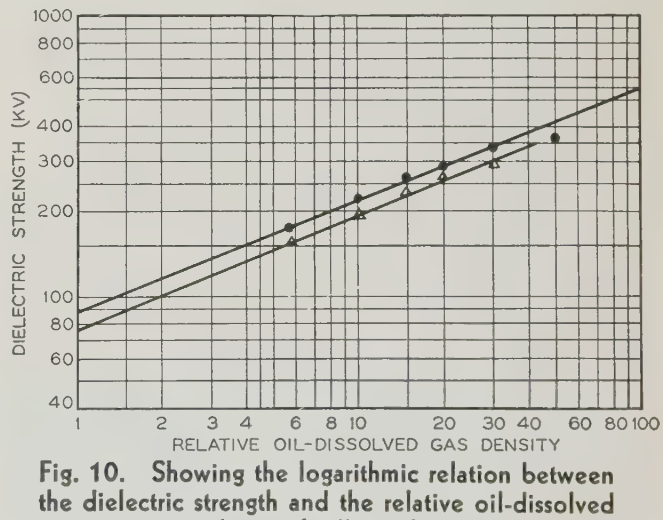


Fig. 10. Showing the logarithmic relation between the dielectric strength and the relative oil-dissolved air density for "petroleum"

Experimental data (Kock) from figure 9

get away from each other so that they finally become distributed uniformly in the solvent. There is, however, a difference between a gas and a dissolved substance, which has been expressed in the statement that the molecules in the gaseous state do not need a solvent to hold them in suspension in a certain volume; their mutual repulsion is enough for the purpose. On the other hand, when a solid, liquid, or gaseous substance is dissolved in a solvent, its molecules would not remain in the limited volume "if they were not united by their affinity to the molecules of the solvent."

It is the analogous behavior of the gaseous and the dissolved states of matter necessarily modified by the affinity of the molecules of the solute for the molecules of the solvent, which appears to determine the dielectric breakdown of "impure" liquid dielectrics.

Correlation of Pressure and Temperature Effects

In the preceding paragraphs, it has been shown that the temperature effect on the breakdown of "impure" liquid mineral oil dielectrics is a logarithmic function of the relative oil-dissolved gas density. In like manner it has been shown that the pressure effect on the dielectric strength is also a logarithmic function of the relative oil-dissolved gas density. The relationship has been expressed as

$$Kv = AD^n \text{ for temperature change} \tag{2}$$

$$Kv = AD^n \text{ for pressure change} \tag{3}$$

For mineral transformer oils, $n = 0.55$

The identity of these relations demonstrates the value of D in determining the dielectric strength of "impure" mineral insulating oils. Equation 2 has been shown to apply to oils showing either a rising or a falling dielectric strength with temperature. It has also been applied to an oil tested over a sufficiently broad temperature range such that the dielectric strength first rises and then falls as the testing temperature is increased. Formula 3 has been applied to transformer oil over an air pressure range as high as 60 atmospheres. The factor D correlating the behavior of oil under varying temperatures and pressure conditions, has been defined as the relative oil-dissolved gas density.

Further Application of the Concept of Relative Liquid-Dissolved Gas Density

Sufficient data are not at hand to determine the validity of the relation

$$Kv = AD^{0.55}$$

for all insulating liquids. The exponent (0.55) may vary from liquid to liquid, being affected by the molecular gas solution phenomena. It is obvious that where molecular association in solution occurs, such variation would be expected. Chemical reaction in solution would also involve deviations from the relation derived.

Figures 9 and 11 show the dielectric strength-pressure relation for benzol and "petroleum." Figures 10 and 12 demonstrate the logarithmic relation between the liquid-dissolved air density and the dielectric strength. The value of the exponent n varies somewhat from the value obtained for transformer oil. The relations are expressed as

$$Kv = AD^{0.25} \text{ for benzol} \tag{4}$$

$$Kv = AD^{0.41} \text{ for "petroleum"} \tag{5}$$

The dotted lines shown in figures 9 and 11 show the application of the logarithmic relations 4 and 5.

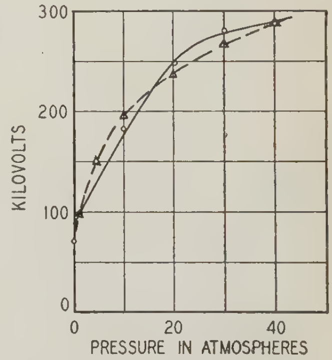
Further experimental work is necessary before the universality and exact value of the exponent n can be claimed.

The Mechanism of "Impure" Liquid Dielectric Breakdown

It has been suggested in a previous publication[1] that the dielectric breakdown of gas-containing dielectric liquids may involve the actual separation of the liquid-dissolved gas from the "impure" dielectric solvent, with resultant breakdown in a manner clearly distinguishing the "impure" from the "pure" insulating liquid. There is considerable reason to believe that such separation may occur. It is to be observed, however, that gas separation from solution is not necessarily involved. The close physical and electrical analogy between gaseous and dissolved states, modified as may be necessary by the forces of

Fig. 11. The effect of air pressure on the dielectric strength of benzol

Solid line is based on the experimental data (circles) of Kock (reference 7)
Dotted line—calculated from the logarithmic relation of figure 12



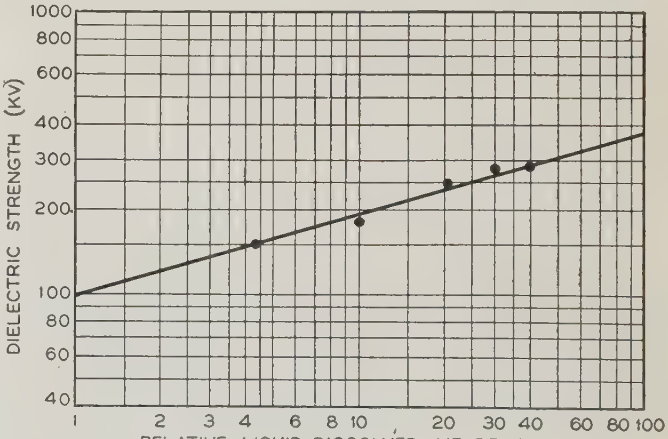


Fig. 12. Showing the logarithmic relation existing between the relative liquid-dissolved air density and the dielectric strength of benzol

Based upon experimental data of Kock (reference 7)

molecular solution, appears to indicate that liquid-dissolved gas may influence the breakdown of the "impure" liquid dielectric without actual gas separation. Further experimental investigation is in progress, the object of which is the solution of this problem.

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Noise Measurements for Engineering Purposes

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The 2 principles of noise measurement, namely, the subjective and objective principles, are discussed in this paper with special reference to electrical plant. Two forms of measurement embodying the subjective principle are considered: One is the proposed primary standard method, which is essentially a laboratory method; the other is the noise audiometer, which enables the subjective principle to be applied directly to the study of engineering noise problems. A form of audiometer and technique, together with their practical advantages, are described. The objective method of measurement is particularly needed for commercial acceptance tests. The evidence shows that the objective type of instrument now available evaluates the noise of many types of plant correctly, but that with noises predominantly harmonic in tone structure, the principle of the method is inapplicable. It is concluded that the audiometer provides the only practicable means at present available for measuring transformer noise and that no satisfactory solution for the commercial testing of such apparatus has yet been reached.

In industrial noise problems, particularly those arising in the electrical industry, a great variety of noises is met. For measuring such noises, the ideal instrument would be one that would indicate by means of a meter deflection the loudness of a noise of any type in terms of an accepted primary standard. The ideal instrument would have to simulate in a complete manner the response of the ear to noises of all types and complexities. A necessary preliminary to the production of such an instrument would be a complete understanding of the response of the ear to complex sounds, with means of predicting quantitatively their total loudness. At present much has yet to be learned about ear response, and so far no generally valid method of computing the loudness of complex sounds appears to have been advanced. Nevertheless, objective noise meters based upon simple assumptions have been developed empirically, as is well known, and these instruments go a long way toward meeting practical needs. However, in certain important noise problems in electrical engineering the basic principle of the objective instrument fails, and instruments of this type must be used with discrimination. The subjective or aural comparison method of measurement need involve no assumptions regarding ear response and, within certain limits, this method measures correctly any sustained noise. In its portable form and with the use of a suitable technique, it has been found technically satisfactory and convenient; however, it does not possess certain practical advantages of the objective method. The purpose of the present paper is to examine the suitability of each method of measurement for different problems that arise in engineering. In the author's opinion both subjective and objective methods should be used in the laboratory, factory, and field, and constantly compared, in order to insure that both aspects of

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noise are given adequate attention. In order to see the subject in proper perspective, it is advisable first to consider briefly the primary standard for sound measurement.

Primary Standard for Sound Measurement

The setting up and use of a primary standard for the calibration of noise measuring instruments is essentially a laboratory matter. It requires special facilities, and a rigorous experimental technique is necessary in order to remove all doubt as to the validity of the measurement. The standard that almost certainly will be agreed upon for international use is a plane or spherical sound wave having only a single frequency of 1,000 cycles per second, or, in other words, a 1,000 cycle pure tone in free space. The loudness of the sound to be measured, which may be called X, can be compared with that of the standard only by the ultimate criterion of relative loudness, namely, the introspective judgment of a representative group of observers. A consideration of this matter[1] shows that for the highest precision it is desirable that observers do nothing but judge which of 2 sounds presented is the louder. Judgments of equality are not used. Observers are not allowed to make adjustments or to know the results of their own or other observers' judgments. The test tones are controlled by independent operators who adjust them to intensities unknown to the observers. Careful precautions are taken against fatigue. Several observers, *e. g.*, 9, are employed and the standard tone and X are heard alternately with both ears, the observer facing the source. The judgments then are treated statistically and the intensity of the standard that is judged to be as loud as X is deduced.

In this way any type of sustained noise may be measured in terms of the primary standard. If observations of X are made also with a portable noise meter, the calibration of the meter for that type of noise can be deduced.

With this rigorous technique, which for brevity can be called the statistical technique, individual judgments show considerable dispersion. In the paper referred to, a spread of about 13 decibels is shown, apart from one isolated case of 24 decibels. Geiger and Abbott[2] report that the spread of their observations, taking all observers into account, varied from 13 to 31 decibels (their technique was not precisely the same as that just described). Hence in order that sufficient precision may be obtained in the final result, the statistical technique, which is entirely necessary and appropriate for fundamental measurements, requires a considerable number of subjects. Also considerable time is required to obtain a measurement.

The Subjective Method for General Noise Measurements

It would appear that the cumbersome nature of the statistical technique and the uncertainty in individual observations has led to the impression that subjective methods of measurement are, in general, unsuitable for engineering purposes. However, experience shows that this is not necessarily true, provided that suitable apparatus and technique are employed.

In view of the fundamental nature of the aural comparison method, the author and his colleagues have thought it essential to make the method conveniently available for everyday measurements in the laboratory, factory, or field. The liberal use of the aural balance method in a suitable form seems a necessary step in the evolution of a satisfactory basis for commercial noise measurements, whatever principle of measurement or form of instrument eventually may be adopted.

Portable aural comparison instruments are not new, and several forms and measuring techniques have been devised. The author and his colleagues have studied the factors entering into aural comparison measurements and have evolved a form of instrument and a technique which have been described elsewhere.[3] There is no need to give in detail here the steps that led to the instrument and technique adopted; these may be found in the original paper.

A Noise Audiometer for Industrial Measurements

General Principle. A pure rather than a complex reference tone is employed, as it is capable of simple and precise definition and reproduction. For reasons that will be apparent later, there are special objections to reference tones with harmonic components. The apparatus must be easily portable and capable of use in a wide variety of surroundings. Hence a free space reference tone set up by a loudspeaker is impracticable. As the range of industrial measurements normally extends up to 110 decibels above 0.0002 dyne per square centimeter, the production of a pure reference tone up to that intensity is a further reason for using telephone receivers.

The presenting of the reference and unknown sounds to the observer simultaneously rather than alternately is clearly a practical necessity as, in general, the unknown sound cannot be interrupted suddenly. Means must also be provided for adjusting and observing the intensity of the reference tone in relation to that of the unknown sound. The reference tone frequency should be in the middle region, say, between 700 and 1,000 cycles per second. The standard frequency of 1,000 cycles may be used, but a somewhat lower frequency, *e. g.*, 800 cycles, has the advantage of being nearer the average frequency of the noise emitted by machinery in general and is therefore slightly easier to match with machinery noise. Also an 800 cycle tone may be compared directly with the standard 1,000 cycle tone without difficulty. The reference tone is applied to one of the observer's ears by means of a close fitting cap on the receiver, the other ear being turned toward the unknown noise. The spaced-telephone technique is not used on account of the baffling of the ear to the unknown sound by the receiver, which produces a frequency-discriminating effect. There are

1. For all numbered references see list at end of paper.

also other objections to the spaced-telephone technique.[3] Furthermore, an excessive receiver input would be required to produce an intensity of 110 decibels with a spaced receiver.

Apparatus. The reference tone is generated by a battery-operated valve oscillator giving a pure wave form. The voltage is applied to 2 attenuators, the output current of which is applied to the telephone receiver. The voltage applied to the first attenuator is observed by means of a miniature voltmeter and is adjustable over a small range by means of a rheostat controlling the valve filament current. Adjustment in larger steps is provided on the high voltage battery. The main attenuator is adjustable from 0 to 100 decibels in 5 decibel steps. The auxiliary attenuator is continuously adjustable from from $+6$ to -5 decibels. By temporarily doubling the normal working voltage, intensities up to 112 decibels can be obtained if required. The selection of the telephone receiver is an important matter. The form used is tuned mechanically to 800 cycles per second, which not only decreases the oscillator output required for a given intensity, but also further purifies the tone produced. The tuning is adjusted under the acoustical conditions obtaining when the receiver is worn on an observer's head. The receiver is provided with a close-fitting soft-rubber cap. This cap effectively seals the ear to which the reference tone is applied against the entrance of other sound; it also minimizes the possibility of direct conduction of sound from the body of the receiver to the head. The receiver used has a linear characteristic up to 112 decibels as shown by acoustical pressure measurements. The whole apparatus is contained in one box $7^3/_4 \times 14 \times 6^3/_4$ inches, the total weight being $16^1/_2$ pounds. A carrying strap is provided, which can be extended to pass over the shoulder of the observer so that measurements can be made while carrying the instrument.

Method of Using Noise Audiometer. Bearing in mind the statistical laboratory technique, the following technique is used: A single observer making equal loudness judgments is employed. The oscillator is switched on and the output voltage adjusted to the standard value. The telephone is adjusted on one ear, the other being turned toward the source of sound to be measured. It is found that the sideways position facilitates concentration of attention on the sound under observation. When extraneous noise is present, or when because of surrounding conditions the sound field unavoidably is distorted, it gives a bias in favor of the sound under observation. The facing position can be used if desired, but in general the calibration will be altered slightly. The attenuator with the coarse setting is adjusted until the reference tone is appreciably louder than sound X and the setting mentally noted. The reference tone then is made appreciably softer than X and the setting noted. By successive trials the observer narrows down the interval between the 2 settings to within 5 decibels. Leaving the attenuator with the coarse adjustment set at the nearest stud, he completes the aural balance as nearly as he can by the attenuator with the fine adjustment. Thus by a series of converging adjustments a final setting is reached at which the observer is equally aware of the standard and sound X. The process is repeated with the reference tone applied to the other ear and the mean of the 2 final settings taken as the considered judgment of that observer. The justification for this technique will be discussed after instrumental errors have been considered; but for the present it may be noted that in measuring the complex sounds ordinarily met in engineering problems, the spread of the mean final settings of the observers normally does not exceed ± 2 decibels at 100 decibels level, ± 4 decibels at 80 decibels, and ± 6 decibels at 50 decibels. With pure tones the spread is larger, as will be seen later.

Sources of Error. Before the free-space primary standard had been formulated, the calibration of the noise audiometer was carried out on the following lines: The reference pressure for the 800 cycle reference tone was taken as 0.000215 dyne per square centimeter for an observer facing the source. This is the mode threshold value given in table I of reference 3. In order to relate this free-space pressure with that set up in the ear canal of an observer, a series of measurements was made on 10 subjects by means of a microphone fitted with a fine nonresonant probe tube. The combination of probe tube and microphone was calibrated by placing the end of the tube in a known sound field, i. e., at the front of another microphone the field calibration of which was known accurately. It was demonstrated that the presence of the probe tube did not appreciably alter the field. In the observations on the 10 subjects it was found that the pressure at the entrance to the ear canal was higher than the field pressure, the excess varying from 2 to 4 decibels with an average of 3 decibels. The canal pressure corresponding to 0.000215 dyne per square centimeter therefore was taken as 0.00030. (It should be noted that the difference between canal and field pressures at 800 cycles shown by figure 10 of Sivian & White's recent paper[4] is about 6 decibels, but as this difference is measured only indirectly the figure of 3 decibels has been adhered to.)

The next step is to find the setting of the audiometer voltmeter that corresponds to the required canal pressure. For this purpose a probe tube connected to a microphone was fitted into a soft rubber cap of the type used on the receivers. The probe tube is calibrated for canal pressure measurements by fitting the cap to a receiver and forming a sealed cavity by placing against it the working face of a calibrated microphone. A known pressure thus is obtained in the cavity and the indications of the microphone fitted to the probe tube are noted. To calibrate the audiometer, the receiver with the cap fitted with the probe tube is placed on the ear of a representative person and the audiometer attenuator set at 70 decibels. The oscillator voltage then is adjusted until a canal pressure of 0.947 dyne per square centimeter is recorded by the probe tube microphone and the voltmeter reading noted. It was found that the variations in pressure set up for a given receiver input attributable to differences in the acoustical impedance of the ears of different persons did not exceed 0.5 decibel. The reproducibility of the

generated pressure with a given person showed variations not exceeding 0.1 decibel without any particular care in the adjustment of the receiver on the head.

Tests were made on the efficacy of the sealing by the rubber cap, in order to ascertain whether sound other than that of the reference tone could be heard by that ear. Pure tones of various frequencies in free space were set up and the thresholds of a subject noted. Standard receivers then were placed on both ears and the threshold again determined. The mean threshold shifts of 4 subjects are given in table I from which it may be seen that the sealing is very effective.

Tests also were made to ascertain whether appreciable sound transmission other than by the air pressure pulsations took place. The hole in the front of a receiver was sealed and it was found that the input had to be increased by 60 decibels above threshold before the reference tone was audible. Direct transmission to the head is therefore negligible. It is known that the attenuation through the head is of the order of 50 decibels. Since under conditions of aural balance the equivalent intensities are equal, the 2 ears may be regarded as independently receiving the reference tone and noise under observation, respectively.

Table I—Effectiveness of Sealing Provided by Rubber Caps

Frequency, Cycles per Second	Threshold Shift, Decibels
100	11
200	10
400	11
800	22
1,600	15
3,200	37
6,400	29

All receivers are checked for linearity of characteristic up to 112 decibels for effects of temperature changes when worn on an observer's head and for secular change before being passed for use. The latter variations do not exceed 1 decibel.

Calibration in Terms of Primary Standard. Since the formulation of the primary standard, the opportunity has been taken to calibrate the noise audiometer in terms of it. The standard specifies listening with both ears to a tone in free space, the observer facing the source. Comparison of this tone with another sound also in free space, involves the statistical technique with alternate listening. Therefore complex sounds of various types might be set up and evaluated both with the primary standard and with the audiometer. This, with the difference that equality of loudness judgments and an 800 cycle standard tone were used, already has been done for motor and transformer noise, the results being given in table 8 of reference 3. Motor noises of 81 and 58 decibels above threshold and transformer noises of eighty-six and 45 decibels were examined. Four practiced observers were employed and the mean of their observations did not show any serious divergence between the noise evaluated in terms of the 800-cycle free-space tone and the audiometer, the largest difference being 6 decibels. The spread of the loudness equality judgments by simultaneous listening did not exceed 4 decibels (45 decibels transformer noise) whereas with alternate listening the spread reached 11 decibels with an 86 decibel motor noise. West[3] has pointed out that the simultaneous listening values yield on the whole results 1 or 2 decibles higher than for alternate listening, and has obtained differences of 2 to 3 decibles.

In calibrating a noise audiometer directly in terms of different types of noise it is difficult to insure that all important types have been covered. It seemed probable that any variation in the audiometer calibration, in terms of the primary standard, as between one type of noise and another would be dependent mainly on the frequencies of the important components of the noise. With the audiometer, the reference tone is presented to the auditory mechanism solely by the pressure pulsations set up in the ear canal. However, the complex sound under observation not only sets up pressure pulsations in the ear to which it is presented but the surface of the head also acts as a collector of sound. As the head is turned sideways to the sound, the surface presented is considerable, and the collecting power certainly will be dependent in some degree on the frequency of the incident sound. In the first place the audiometer therefore was calibrated directly in terms of pure tones of selected frequencies.

The measurements were made in a lined test room[5] 24x24x13 feet, inside dimensions. An electrodynamic loud-speaker mounted in a large baffle was set up in one corner of the room so that sound was radiated toward the center. Irregularities from wall, floor, and ceiling reflection were shown by

Table II—Calibration of Audiometer for 80 Decibel Level in Terms of 1,000 Cycle Tone

Frequency of audiometer reference tone, 800 cycles per second. Number of observers, 10. Reference pressure, 0.0002 dyne per square centimeter

1 Test Tone Intensity Level in Terms of 1,000 Cycles, Db	2 Test Tone Frequency, Cycles per Second	3 Test Tone Intensity Level, Db	4 Mean Corrected Audiometer Reading, Db	5 Difference Col. 4—Col. 1	6 Deviations, Db Max. +	 Max. −	 Mean	7 Intensity Level of Largest Harmonic, Db
80	103	82	79	−1	7	9	3	37
80	219	80.5	81.5	+1.5	7	21	8.1	34
80	370	80	82	+2	7	11.5	5.0	34
80	1,000	80	83	+3	7	9.5	3.4	42
80	3,000	74	81	+1	3	3	1.8	20
80	6,000	84.5	82	+2	8	7.5	4.4	$\ngtr$30

microphone measurements to be negligible because of the large amount of absorption present, the entire room being lined with a 6-inch thickness of cotton waste spaced 6 inches from the walls. The double brick wall construction and the location of the building gave entire freedom from extraneous noise. The acoustical pressure measurements rest on the following basis: The type of condenser microphone employed is $2^1/_2$ inches in diameter and has a flush face, so that cavity resonance effects are absent. Pressure calibration is carried out in terms of the Rayleigh disk in a resonant tube.[6] The field calibration is derived from this by means of probe tube measurements, using a substitution method, and is checked by Rayleigh disk measurements in a lined testing cabinet.

The audiometer to be calibrated was placed on a stand together with an attenuator controlling the test tone, so that either could be manipulated by an observer whose head was somewhat farther than 1 meter from the source. The test tone attenuator was calibrated for intensity at a given frequency by swinging a microphone into the position of the observer's ear that was presented to the test tone, and measuring the absolute pressure. The microphone, in conjunction with a sound analyzer, also was used to explore the purity of the test tone.

It is clear that the conclusions reached in regard to the calibration of an audiometer at different frequencies depend upon the equal-loudness relations with respect to frequency that are assumed. The equal-loudness relations hitherto used by the author and his colleagues consist substantially of Kingsbury's data modified by some experiments of their own, and are given in reference 3. Another set of relations is provided by the proposed U.S. standards.[7] These have been determined by a more rigorous method than has hitherto been employed. However, certain unexplained irregularities and disagreement in certain respects with other data do not allow it to be supposed that finality in this matter has been reached. Nevertheless, they are probably more generally valid than any previously put forward and are used for comparison in the present paper.

Calibrations were carried out principally with test tones adjusted to give an audiometer reading of approximately 80 decibels. The test tone of selected frequency was adjusted to a suitable value and the audiometer set at zero. The observers then were asked to "measure the test tone" by means of the audiometer, or, in other words, to obtain an aural balance with the test tone using the normal audiometer technique including the taking of readings with first one ear and then the other presented to the test tone. No observer had any information as to the nature of the tone he was asked to measure nor was he aware of results obtained by other observers. Ten observers were employed. Observations also were made by setting the audiometer tone and varying the test tone, but no significant difference was obtained. The results are given in table II. For convenience in comparison, the results have been corrected to the 80-decibel equal-loudness contour. They are corrected also for the difference in the observer's sensitivity when facing the source and when turned sideways to it, respectively. Column 7 gives the intensity level, in terms of 1,000 cycles, of the largest harmonic present in the test tone, so that a comparison with column 1 indicates the purity of the test tone. Column 5 gives the divergencies between the audiometer indications and the equivalent 1,000 cycle intensity of the test tone, which are seen to be small. If the 80 decibel contour be assumed to be correct, it is seen that the audiometer reads about 2 decibels high, except at the lowest frequency.

Table III—Comparison of Values of Harmonic Noise* as Determined by Several Different Methods

	Decibels		
	Test A	Test B	Test C
Primary standard, Mean	61	72.5	..
Deviations { Max. +	4	4.5	..
Deviations { Max. −	4	3.5	..
Audiometer, Mean	64	74	81.5
Deviations { Max. +	3	4	2.5
Deviations { Max. −	4	5	4
Number of observers (4 practiced, others unpracticed)	8	10	10
Objective meter (weighting 40 db U.S. contour)	40	46	56.5
From analysis and energy summation (U.S. contours)	36	41.5	..
Mean audiometer − mean primary standard	+ 3	+ 1.5	..
Audiometer, Max. error of any observer	+ 6	+ 5.5	..
Objective meter − mean primary standard	−21	−26	−25

* Core of 4 per cent silicon steel magnetized at 50 cycles per second.

A set of observations at 60 decibels level also was carried out with similar results, the audiometer readings being found to deviate from the 60-decibel equal-loudness contour by +4 decibels on an average. It was intended to carry out observations at 100 decibels level, but the difficulty of producing sufficiently pure tones of that intensity precluded this. Taking this and the previously quoted evidence into consideration, it has been decided for the present to apply an empirical correction of −4 decibels at 60 decibels and −2 decibels at 80 decibels to audiometer readings. Finally experiments were carried out on a harmonic noise, which was measured both in terms of the primary standard using the statistical technique and by the audiometer. An objective meter also was set up and used to measure the noise. A complete analysis also was taken, from which the summed equivalent energy could be computed. The results are given in table III. At 61 decibels level, the mean of the audiometer observations gives the absolute value to 3 decibels, and at 72 decibels level to 1.5 decibels. The spread of the primary standard observations is satisfactorily small and no difficulty was encountered in using the specified technique. It is seen that any audiometer reading gives the mean audiometer reading to 4 decibels at 61 decibels level, 5 decibels at 72 decibels, and 4 decibels at 81.5 decibel (audiometer) level. Also any audiometer reading gives the absolute value to 6 decibels at 61 decibel level, and 5.5 decibels at 72 decibels. The absolute accuracy at higher levels is probably greater, but could not be checked because a standard tone of the required intensity and purity was not available. It should be noted that these results are not confined to skilled observers.

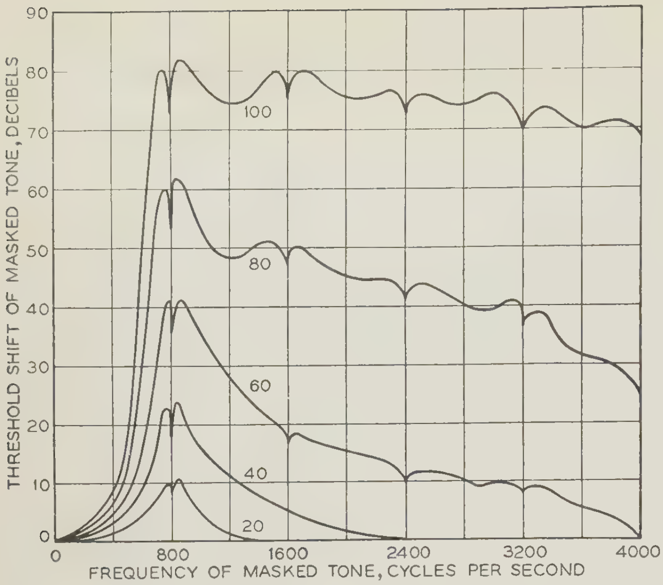

Fig. 1. Masking of one tone by another

Numerical designations on curves indicate intensity level of masking tone in decibels above threshold value (Wegel and Lane)

The question of the consistency of audiometer readings, about which so much doubt has been expressed, is illustrated further by table 10 of reference 3 which gives some figures obtained by beginners. These figures and those given in this paper bear out the order of consistency mentioned in a previous section of this paper, *viz.*, ±6 decibels at 50 decibels, ±4 decibels at 80 decibels, and ±2 decibels at 100 decibels. This experience by no means is confined to the author and his associates. Where the type of audiometer described has been used by others, inquiries have been made as to the agreement between observers in normal engineering measurements and it has been found that their own experience is confirmed. Two factors appear to contribute to this result. The necessity of memory retention with alternate listening tends to increase the spread compared with simultaneous listening. The large spreads that frequently appear when pure tones are measured seem to be attributable to local irregularities in the equal-loudness contours of individuals, as individual observations are reproducible. The much smaller spreads obtained when measuring complex noises appear to be attributable to a modification in the subjective contribution of one component not greatly affecting the total result.

The Objective Method of Noise Measurement

General Principle. As is well known, the objective instruments at present in use operate on the following general principle: A microphone is placed in the sound field under observation and the electrical output of the microphone amplified. The amplified current then is passed through a weighting network and then through an indicating meter which will be assumed to operate on an effective or root-mean-square basis. The weighting network is so adjusted that the over-all response of the instrument is greatest at those frequencies at which the ear is most sensitive. The adjustment is based upon accepted equal-loudness relations. The adjustment is made with respect to 1,000 cycles and a reference pressure approximating the threshold of persons of normal hearing. Hence if pure tones of different frequencies be presented to the instrument, it will indicate the equivalent 1,000 cycle values if the weighting is carried out correctly. The instrument generally is calibrated to indicate directly equivalent 1,000 cycle intensities in decibels above the reference intensity. The required weighting depends to some degree upon the intensity of the tone presented as well as on its frequency, and adjustment in a few steps is provided to allow for this. The instrument is made in various forms and sometimes is combined with a sound analyzer, which is particularly convenient for the study of engineering noise problems. However, it is more with the underlying principle than with particular forms of this instrument that this paper is concerned.

The use of this type of instrument to measure complex sounds implies the following assumptions: (1) that a pure tone that alone appears as loud as another pure tone still appears so when tones of other frequencies, harmonically or otherwise related, are present; (2) that the loudness of a complex sound is equal to that of a series of pure tones of a common frequency and severally equal in loudness to the components of the complex sound; and (3) that the law of summation of such a collection of pure tones is known.

With a meter indicating effective values, the operation of the instrument amounts to taking the sum of the energies of the equivalent tones of common frequency and expressing it as a pure tone of that frequency. It seems probable that the first assumption holds for the important components of a noise, but it is not true for the small ones because of selective masking. The second assumption is certainly often untrue as it neglects the subjective sum and difference tones that are formed by each component with every other component present. The third assumption introduces the question of the relative phasing of the pure tone equivalents. The difficulty does not arise if the ear is responsive to the total energy of these equivalents.

The interest and importance of the objective method lies in the fact that in spite of the incompleteness with which it simulates the response of the ear, it often does give approximate agreement with more fundamental methods. Because of the commercial advantage of a method of measurement independent of personal judgment, it is important to examine how far the objective method can be used in industrial noise measurements, especially those arising with electrical plant.

Applicability to Different Types of Noise. This subject is discussed in a recent paper[3] by the author and 2 of his colleagues. The main conclusions reached will be given briefly here, together with some additional evidence since obtained. Allusion already has been made to sum and difference tones, which are the inevitable result of the nonlinearity of

the ear. In certain classes of electrical plant they assume great importance. The principle of operation of the present objective noise meters makes no provision for the effects to which such tones give rise.

In 1924 Wegel and Lane[8] carried out experiments on the masking of one tone by another. Imagine a pure tone at an intensity just sufficient for audibility in a quiet room. If a second or masking tone of considerable intensity be sounded, the first tone becomes inaudible and its intensity level must be raised by a certain amount before it can be heard again. Figure 1 shows the results of Wegel and Lane's experiments. In the experiment illustrated by the bottom curve the masking tone of 800 cycles was kept at an intensity level of 20 decibels above threshold. As the frequency of the masked tone is increased, the degree of masking, as indicated by the threshold shift of the masked tone, increases to a maximum and then abruptly decreases to a lower value, increasing again and finally decreasing to zero. When the intensity of the masking tone is raised to higher levels, it may be seen that new kinks appear in the curves at certain frequencies. The kinks occur when the masked tone is equal in frequency to the masking tone or when it is a harmonic of the masking tone. When exact harmonic frequency relation is obtained, the masking is somewhat smaller than for a frequency relation slightly removed from exact harmonic relation. These effects result from the correspondence in frequency between the subjectively formed overtones of the masking tone and the masked tone. Hence it is to be expected that when 2 tones of given intensities are sounded simultaneously, the total loudness will be greater when their frequencies are in exact harmonic relation than when they are slightly removed from this relation. When a complex sound consists of several harmonically related tones, there will be many opportunities for the reënforcement of the physically present components by those formed subjectively, and a considerably enhanced total loudness is to be expected.

Attention was called to the importance of this phenomenon in relation to transformer noise by a letter to *Nature*, September 1933 (volume 132, page 350). In the subsequent paper[3] comparisons are given for different types of electrical apparatus of aural balance measurements made by the method described in a previous section of the present paper and the sum of the energies of the equivalent 800 cycle tones, i. e., the value that an objective meter yields. The frequencies and intensities of the components of the various noises were obtained by means of a sound analyzer accurately calibrated for free space measurements. They then were converted into equivalent 800 cycle decibels above threshold by the equal loudness relations given in the paper. The general conclusions reached may be summarized as follows: For noises not predominantly harmonic in character, *e. g.*, turbine-generator sets, induction motors, motor driven fan, the subjective values are from 1 to 10 decibels higher than the objective values; or, if the empirical correction of −2 decibels is applied to the subjective values, the discrepancies vary from −1 to +8 decibels. For harmonic noises, *e. g.*, the noise from transformers, the objective values were of the order of 30 decibels lower than the subjective values. Full particulars are given in table III of that paper. In order to confirm that the large discrepancies met in transformers resulted from the harmonic character of the sound, tests were carried out on synthetic sounds produced with a loud speaker in the laboratory. Table V in the paper referred to gives the results of these experiments in detail. With nonharmonic tone combinations, discrepancies between subjective and objective values from −4 to +6 decibels were obtained. For harmonic combinations of 2 tones, the subjective values were 2 to 5 decibels higher than the objective values, but with large numbers of components discrepancies up to 38 decibels were obtained.

It was shown that the enhancement of loudness with purely harmonic sounds was greater at low physical intensities than at high. For instance, in reference 3, table V, examples appear as follows: A harmonic sound of 12 components and a fundamental frequency of 500 cycles per second had a summed equivalent energy of 83 decibels above threshold in terms of 800 cycles. Its subjective value was 96 decibels giving a discrepancy between subjective and objective values of 13 decibels. On reducing the objective value to 48 decibels, the

Table IV—Comparison of Subjective and Objective Methods of Measurement; Nonharmonic Noise From Experimental 2,000 Horse Power Turbine Driving Brake Through Gearing

Test A: Frequencies of Components, Cycles per Sec	Test A: *Db Above Threshold M	Test A: *Db Above Threshold N	Test B: Frequencies of Components, Cycles per Sec	Test B: *Db Above Threshold M	Test B: *Db Above Threshold N
53	78	88	64	90	92
155	77	83	150	65	76
385	85	85	260	81	78
400	78	79	295	76	78
760	86	86	400	69	72
860	75	75	780	75	75
930	74	74	890	67	67
1,160	72	72	2,350	99	94
1,300	77	77	3,100	101	93
1,540	78	78	3,700	105	96
1,950	86	85	5,000	96	90
2,370	95	91	8,000		
2,500	99	94			
3,100	99	91			
3,700	96	87			
4,750	87	78			
6,200	99	88			
9,900	83	70			
Equivalent energy summation (Objective values)	105.2	99.2		107.6	100.5
Largest components	99	94		105	96
Audiometer values (subjective values):					
Observer 1	100			105	
Observer 2	101			105	
Mean	100.5			104.5	
Mean audiometer value minus calculated value:					
M	−4.5			−3	
N	+1.5			+4	

* Intensities of components given as decibels above threshold of equally loud 800 cycle tone. *M* denotes values calculated on basis of equal-loudness relations of reference 7 (U. S. proposals); *n* on basis of reference 3.

physical structure of the tone being unchanged, the subjective value fell only to 86 decibels giving a discrepancy of 38 decibels.

In another case it was shown that with a harmonic sound having a large fundamental of 108 cycles per second, the energy contribution of the harmonics was negligible. However, by removing the harmonics, which left the objective value unchanged, the subjective value of 100 decibels was reduced by 12 decibels.

Apart from equivalent energy summation from analysis, an objective noise meter adjusted in accordance with the equal loudness relations used gave general confirmation of these results. These experiments were regarded as confirming the anticipation that because of its principle of operation the objective or weighted network noise meter would give indications of the wrong order of magnitude for predominantly harmonic sounds, such as those emitted by transformers. However, in view of the importance of the objective method for commercial measurements, some further consideration of the matter seemed advisable. It is evident that the indications of objective meters or the computation of the summed equivalent energy of complex sound are entirely dependent on the basis on which the weighting with respect to frequency is carried out. As previously mentioned, the equal loudness relations hitherto used by the author and his colleagues consist of Kingsbury's data modified by some experiments of their own, and are given in reference 3.

The equal loudness contours of the proposed U.S. standards[7] are now also available. To show that the conclusions in regard to the use of the objective method in measuring harmonic noises are not materially affected by the equal loudness data used, results computed from both will be given in a few cases.

Table IV shows the results of subjective measurements and noise analysis of a nonharmonic noise typical of those met in engineering problems. A 2,000 horse power turbine loaded by means of a brake through gearing consisting of several stages was set up in a works testing department. Tests *A* and *B* correspond to different conditions of operation, which need not be discussed here. The noise emitted by the set-up in test *A* may be considered substantially nonharmonic because while 2 series of harmonics are obviously present (i. e., 760, 1,540, 3,100, 6,200 and 2,370, 4,750 cycles per second), the presence of so many other large and nonharmonic components is sufficient to diminish greatly the harmonic effect. In test *B* the harmonic series (150, 295 and 400, 780 cycles per second) are small in intensity and have no appreciable effect. In order that the normal consistency of audiometer measurement of complex sounds may be illustrated, the readings of individual observers are given. Practiced observers were employed. In tests *A* and *B* it may be seen that at the order of intensity involved,

Table V—Comparison of Subjective and Objective Methods of Measurement; Harmonic Noise From Ring Cores of 4 Per Cent Silicon Steel Magnetized at 50 Cycles per Second

Frequency of Components, Cycles per Sec	*Intensities in Decibels Above Threshold of Equally Loud 800 Cycle Tone: Test 1 M	Test 1 N	Test 2 M	Test 2 N	Test 3 M	Test 3 N	Test 4 M	Test 4 N
100		12.5		10		6		0.5
200	7	19	5	17	13	27.5		6
300	47	55.5	22	32	20	30	26	36.5
400	42	47.5	40	45	30	35.5	23	28
500	42	45.5	35	38.5	57.5	61	22	26.5
600	43	44	38	40	36	37	13	14.5
700	35	35.5	29	29.5	39	39	19	19.5
800	36	36	31	31	34	34	18.5	18.5
900	30	30	29.5	29.5	27	27	16.5	16.5
1,000	28	28	31	31	30.5	30.5	13	13
1,100	25.5	25.5	31	31	32	32		
1,200	33	33	35	35	23.5	23.5	18	18
1,300	29	29	27	27	27.5	27.5		
1,400	28	28	31	31	25	25		
1,500	31	31	27	26	20.5	20.5		
1,600	32	31	31	30.5	27	27		
1,700			42	42				
1,800	46	47			34	35		
2,000					29	27		
2,200					30.5	28		
2,400					32	30		
2,800	34	30						
3,000	37	32.5	40	37				
4,800			31	22				
5,000					26	24.5		
Equivalent energy summation (objective values)	52.2	57.3	47.7	49	57.7	61	30.2	37.7
Largest components	47	55.5	42	45	57.5	61	26	38
Audiometer values (subjective values):								
Observer 1	85		85		87		67	
Observer 2	84		83		86		63	
Mean	84.5		84		86.5		65	
Mean audiometer value minus calculated value:								
M	32		36		29		35	
N	27		35		25		27	

*M denotes values calculated on basis of equal-loudness relations of reference 7 (U. S. proposals); N on basis of reference 3.

i. e., 100 decibels, agreement to 1 decibel between observers is obtained, which is not unusual. From test *A* the difference between subjective and objective values is −4.5 decibels on the basis of the proposed U.S. standards (*M*) and +1.5 decibels for the equal loudness relations used by the writer (*N*). For test *B* the differences are −3 and +4 decibels, respectively. Hence these are cases in which approximate agreement between subjective and objective measurements is obtained.

Table V gives some results of laboratory experiments on the noise emitted by ring cores of transformer steel, magnetized by conductors passing through the core, but spaced well away from it so as not to interfere with the sound radiated by the core. As may be seen, the noises are purely harmonic. The tone structures in the different tests were obtained by altering the mode of clamping of the core. The flux density was adjusted in tests 1, 2, and 3 to give subjective values of about 85 decibels. It may be seen that in the audiometer measurements the disagreement between the 2 observers employed does not exceed 2 decibels, which is not unusual with complex sounds of about 80 decibels. The disagreement is greater in test 4, but not serious. In all cases the objective value is much lower than the subjective, whether the former be computed on the *M* or the *N* basis. Test 3 is one in which the value of the summed equivalent energy is decided by the largest component, the 500 cycle component in this case. The equivalent energy contributions of all the other components are negligible, that is, the indications of an objective meter would not be affected by them, and yet they can cause the subjective value to be higher than the objective value by about 25 decibels. Comparing tests 2 and 3, the 2 noises are equally loud to within the equivalent of 2.5 decibels and yet their objective values differ by approximately 11 decibels. Neither the objective values N nor the magnitudes of the largest components are any guide to the subjective effects of harmonic noises. Further evidence on the inapplicability of the objective meter to harmonic noise is afforded by table III.

Data on Objective Method From Other Sources. Geiger and Abbott[2] give the results of observations on several different types of noises in terms of a 1,000-cycle free-space tone judged to be equally loud and by a Western Electric objective noise meter. The statistical technique was not used. Instead, the observer adjusted the 1,000 tone to loudness equality with the noise, the 2 sounds being heard alternately. Groups of 10 to 20 observers were used. Taking all observers into account, the spread of their observations varied from 13 to 31 decibels at a level of about 70 decibels. The weighting of the objective meter was in accordance with Kingsbury's 60-decibel equal-loudness contour. The readings of the objective meter compared with the subjective data varied from +0.2 decibels to −4.4 decibels over the whole range of noises examined. That the objective meter should read not more than a few decibels low for sounds not predominantly harmonic in character is in accordance with the author's experience. Geiger and Abbott do not give the compositions of the noises they examined, but several of them (*e. g.*, the "raytheon" noise) one would expect to be harmonic and therefore to show greater discrepancies than 4.4 decibels.

Table VI—Data on Harmonic Sounds Having Components of Equal Intensities in Terms of 1,000 Cycles

Number of Components	Fundamental Frequency, Cycles per Sec	Db of Each Component	Summed Equivalent Energy, Db	Subjective Value, Db	Difference, Col. 5 — Col. 4
2	1,000	20	23	24	1
		40	43	47	4
		60	63	68	5
		80	83	88	5
10	1,000	20	30	41	11
		40	50	63	13
		60	70	78	8
		80	90	94	4
10	50	20	30	36	6
		40	50	53	3
		60	70	73	3
		80	90	93	3
10	100	20	30	42	12
		40	50	60	10
		60	70	78	8
		80	90	93	3
10	530	20	30	45	15
		40	50	70	20
		60	70	89	19
		80	90	103	13

In their paper on the calculation of loudness,[1] Fletcher and Munson give some interesting data on harmonic sounds of a particular kind, *viz.*, those having components of equal intensities in terms of 1,000 cycles. In such cases the summed equivalent energies in decibels may be readily estimated. Table VI summarizes some of these results. As might be expected, the difference between subjective and objective values increases with the number of components. Also the difference is larger for low intensities than for high. The effect appears to be larger for medium and high fundamental frequencies (*e. g.*, 530 or 1,000 cycles per second) than for low frequencies (*e. g.*, 50 and 100 cycles). Also it may be seen that differences up to 20 decibels are shown for a fundamental frequency of 530 cycles and 12 decibels for 100 cycles. The general tendency of these results is in accord with those obtained by the author except that occasionally he has obtained differences of more than 30 decibels with a fundamental frequency of 100 cycles (see table V). There are probably 2 reasons for this. The examples of table V have many more than 10 components, which spread into the middle and high frequency range where the effect appears to be largest. Also the components are by no means equal in equivalent 1,000 cycle intensity. The summed equivalent energy usually is only a few decibels more than the energy of the largest component, and it has been shown previously how harmonic components may have a considerable subjective effect without contributing appreciably to the total equivalent energy of the sound. Hence for sounds having a given number of components and a given subjective value, it is to be expected that the objective value will be lower when the components are of unequal equivalent intensity than when they are equal. These factors would lead to the larger differences that have been observed in transformer noise.

In a recent paper[9] Fletcher has discussed the special properties of harmonic tone combinations or musical tones, using the theory of Fletcher and Munson[1] to derive examples.

Conclusions Regarding Accuracy of Objective Method. The evidence from the various sources considered indicates that the objective type of instrument measures ordinary noises that are not predominantly harmonic in character to within approximately 8 decibels, the error often being considerably less than this. The meter tends to read low in the majority of measurements.

With harmonic noises, the energy summation principle upon which the instrument is based fails and errors of 30 decibels or more are possible, the meter reading low in all cases. Thus the meter can indicate 50 decibels when the correct value is 80 decibels. In terms of loudness (see appendix) the discrepancy is enormous, being the difference between 3.0 and 32. Thus with harmonic noises the objective meter can lead to results of the wrong order of magnitude.

Summary and Conclusions

Primary Standards.[7] The use of a 1,000 cycle pure tone in free space, the listener facing the source and listening with both ears, and the statistical technique for comparing the unknown with the standard tone has strong arguments in its favor. From the author's experience, it seems an entirely adequate final court of appeal.

The proposed equal loudness contours appear to require reconsideration, and it is to be hoped that this will be undertaken in the near future.

With regard to the suggested decibel-loudness relation, it is noted that this is referred to as an "additional" loudness scale for the purpose of estimating percentage reductions in loudness; that is, it is viewed as something extraneous to the accepted decibel-loudness scale and as provided to meet the needs of particular interests. In the author's view, the only scale that can properly be called a loudness scale is one based upon subjective data, and which yields numerical values proportional to the loudness sensation. In other words, a scale of the kind that has been called an "additional" loudness scale would be a real loudness scale. The decibel loudness scale unquestionably gives a measure of a purely physical quantity, the intensity above reference intensity of the equally loud reference tone. In the author's opinion it gives nothing more. It can be called a loudness scale only by the adoption of a very strained line of argument. With regard to the particular decibel-loudness relation suggested, the author doubts whether this is representative of the evidence available and considers that it contains elements that are not fundamental. The whole question is discussed in another paper[10]; see also the appendix of the present paper.

Audiometer Methods. Since aural comparison is the fundamental principle of loudness measurement, it is important, on quite general grounds, that the principle be employed directly in the study of engineering noise problems where possible. Rapid progress in the theory and technique of noise measurement has been made in the past few years. While perfection is still far off, it is reasonable to suppose that progress will continue. If during this evolutionary period the principle is not kept continually active and used, there is danger that much of importance may be missed. A case in point is that of the properties of harmonic tones.

Again, it has been suggested that tones, besides possessing the attributes of pitch and loudness, possess also "volume" and "density."[11] Then there is the question of the "disagreeableness," "annoyance" or "nuisance"[2] attributable to a sound. If an observer can discriminate between these different additional attributes, he presumably can make aural comparison observations in respect of each of them. He cannot obtain information on them from objective measurements.

If everyday noise measurements were conventionalized into the indications of the objective meters at present available, there would be a risk that the whole subject would be seen in wrong perspective.

The aural comparison method embodied in the primary standard is only appropriate to the calibration of instruments for everyday use and for research into the fundamental problems of noise measurement. It is essentially a laboratory method. In the present paper, it has been shown that the audiometer form of the aural balance method can be used for engineering measurements provided a suitable instrument and technique are employed. It yields results in terms of the primary standard. For ordinary purposes, within the limits of ± 4 decibels at 80 decibel level, one observer may be relied upon for the sustained noises met in engineering problems. If necessary, the accuracy can be improved by employing 3 observers and by using practiced observers. A beginner, after a few attempts, usually obtains values agreeing with those of a practiced observer. The method is convenient and quick. Apart from being technically generally applicable, the instrument described has the practical advantages of being unaffected by ordinary electrical or magnetic interference from electrical plant, entirely self-contained, easily portable, of small dimensions, light in weight, and of moderate cost. While the choice of 1,000 cycles per second for the primary standard reference tone frequency is acceptable, there is no need to tie audiometer reference tone frequencies to that value. Many workers have thought that for engineering purposes a somewhat lower frequency is desirable and a frequency of 800 cycles per second gives several small advantages which need not be discussed here. The indications of 800 and 1,000 cycle audiometers are, of course, directly comparable.

Where it is more important to obtain facts than to avoid argument, the aural comparison principle is required. Thus in the author's opinion, for ordinary research or engineering measurements, whether carried out in the factory or the field, a suitable audiometer should be used. If an objective meter is used alongside the audiometer, additional and useful information will be obtained; but only in so far as the objective meter readings are in accord with aural

comparison measurements can the former be accepted.

Objective Methods. The importance of the objective method lies in its elimination of the personal element and the possibility of obtaining a measure of fluctuating noises. It is essential, however, to bear in mind that there is nothing inherently valid about the basic principle of the objective meters now made, *viz.*, the equivalent energy summation. If this simple principle sufficed, there would be no reason for the existence of the elaborate theories of the loudness of complex sounds propounded by Steinberg, Fletcher, and Munson, and by Steudel. Nevertheless, it has been demonstrated that the objective meter yields approximately correct indications for noises not strongly harmonic. From an engineering point of view, this covers turbine-generator sets, generators, motors, fans, and general machinery and such miscellaneous sounds as factory, power station, or street noises. The errors arising with partially harmonic sounds, such as the noise of induction motors, probably can be reduced by calibrating the noise meter for the particular type of noise under observation. This could be done for the factory testing of large numbers of similar machines by semiskilled workers. For commercial acceptance tests, the definition of the type of noise might present some difficulty, but the experience of other workers may throw light on this point.

With strongly harmonic noises, such as those emitted by transformers, reactors, and a-c contactors, the energy summation principle fails and large errors appear. The objective meter reading is no certain guide to the loudness of a harmonic sound and, as has been shown, may not give even correct relative values.

The practicability of eliminating the error by applying a correction to objective meter readings does not seem very great. In many practical cases the correction would have to be large, *e. g.*, 30 decibels in 80 decibels, and it depends on several factors. Acoustically it would depend upon the tone structure, which in turn depends, for transformers, on the flux density, voltage wave form, mechanical construction, and other factors. It may be possible to show from exhaustive tests on transformers of different types that for particular types some rough correspondence exists between subjective and objective values, but it is doubtful whether large corrections applied on such a basis would be generally acceptable. To the author it seems far simpler to make direct audiometer observations of transformer noise, which for purely technical purposes presents no difficulty.

Commercial acceptance tests, which are likely to be contentious, present a real difficulty with transformers and no satisfactory solution is at present available. Where the parties involved are prepared to coöperate unreservedly (such situations are within the author's experience), audiometer measurements can be made by a small group of observers provided and approved by both parties, and, if the spread of the observations is normal and shows no obvious bias, the mean taken as defining the noise of the transformer under agreed test conditions. The employment of observers independent of either party is possible but inconvenient. Beyond doubt objective measurements are desirable for all commercial acceptance tests, but so far as the author is aware no universally applicable objective meter has yet been produced. It is highly important that efforts be directed toward the difficult problem of developing such an instrument so that audiometer measurements, where they are unsuitable, may be eliminated.

No attempt has been made here to discuss the practical conditions of engineering noise tests, as to deal adequately with the subject another paper would be needed.

Appendix—Relation Between Decibels and Loudness

It now is recognized that the decibel scale, used as a loudness scale, does not yield numerical values proportionate to the loudness sensation experienced by a person of normal hearing. Both practical experience and recent published experimental evidence show that loudness increases much more rapidly than the first power of the number of decibels above threshold. Experimental evidence tends to show that the nerve-impulse theory of audition provides an explanation for the well authenticated faculty of making intuitive estimates of relative loudness, which is possessed of most persons. The theory also explains the effects observed when a given stimulus is applied alternatively to one ear and to both ears. Further, relations between decibels above threshold and loudness sensation deduced from the loudness estimates and from monaural-binaural listening experiments are in substantial quantitative agreement.

The final conclusion is as follows: If the number 100 be assigned to the loudness sensation experienced when a 1,000 cycle pure tone stimulus of 100 decibels above threshold (0.00020 dyne per square centimeter) is applied, the loudness L for any other level between 30 and 115 decibels is given with sufficient accuracy for practical noise measurements by the following expression:

$$L = d^5 \times 10^{-8}$$

where d is the number of decibels above threshold. Thus when the decibel observations of practical noise measurements refer to the 1,000 cycle pure tone that evokes the same loudness sensation as the noise under observation, they may be converted immediately to loudness values. Where loudness values are given in this paper, they have been calculated on the foregoing basis.

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Expulsion Protective Gaps on 132 Kv Lines

During the last few years, the expulsion protective gap, consisting of an arrangement of spark gaps inside of fiber tubes and in series with an external gap, has been applied to a few medium voltage transmission lines for protection against outage due to lightning. The first extensive application of such gaps on 2 typical 132 kv lines during the past 2 lightning seasons are presented herewith. These expulsion protective gaps are shown to be an effective device for preventing lightning flashovers of a line and reducing line outage.

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THE problem of lightning protection on high voltage transmission lines can be solved, in theory at any rate, by 3 different methods of approach. These are:

1. Keep the lightning off the transmission line by cloud dispersion or by diverting wires.

2. Over-insulate the line and at the same time reduce the magnitude of lightning voltage to be contended with. This reduction of lightning voltage can be accomplished by properly arranged ground wires in combination with low tower footing resistances and counterpoises.

3. Discharge the lightning current at or near the point of origin. This can be accomplished by letting the lightning current discharge normally, accompanied by the usual dynamic follow-up, but in turn followed by very quick interruption of this dynamic current so that the net effect from a load standpoint is equivalent to no interruption to service. This latter can be done in 2 ways: First, by tripping the affected line and reclosing with high speed oil circuit breakers; and second, by the use of the expulsion protective gap, previously described,[1] which interrupts the fault current in the order of 0.5 cycle, without interrupting the normal flow of power.

This paper deals with the last of these methods, namely, the expulsion protective gap, and more particularly with the application, engineering details, and operating experience obtained on 2 132 kv lines of the Appalachian Electric Power Company, namely, the Glenlyn-Roanoke line 65 miles long and the Roanoke-Danville line 68 miles long. The expulsion protective gaps have been in service on 1 circuit of the first line for nearly 2 lightning seasons and on the second line for 1 lightning season.

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1. For all numbered references see list at end of paper.

Fundamental Requirements for Use on 132 Kv Lines

In applying this particular device to a group of 132 kv steel tower transmission lines, the fact was confronted that the final device had to meet the following specifications:

a. First and fundamentally it had to prevent line (insulator) flashover, and this meant it had to have a lower impulse breakdown than the line insulation.

b. The gap had to interrupt successfully any power current that the particular system could impose on it.

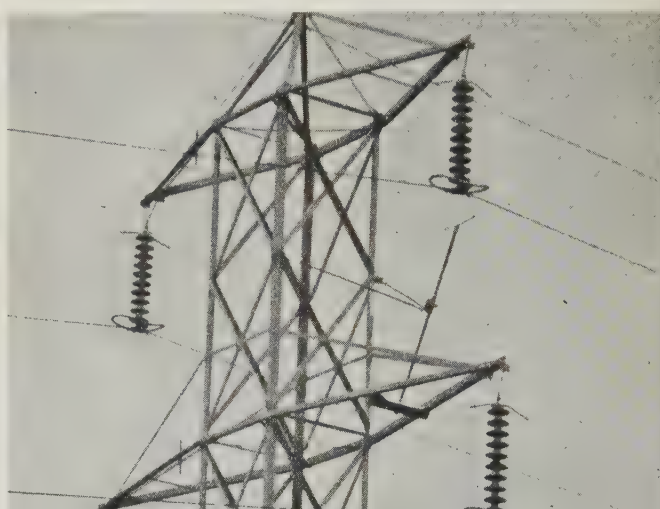

Fig. 1. 30 degree mounting. 132 kv expulsion protective gaps mounted on a suspension tower of the Glenlyn-Roanoke Line

Tube located below the insulators shown on the right, and at approximately 30 degrees to the vertical

c. It was desired that the device stand up well under weather and, if possible, give a life equal to the rest of the transmission line equipment.

d. If the line was to give lightning-proof performance, it appeared essential, that tubes be installed at each tower location. This in turn meant that if the tubes were to be justified from an economic standpoint, that not only did the first cost have to be held down, but that the design would have to be such that the maintenance would be very nominal.

e. It was desired that the appearance of the tower and of the completed line in general, with the tubes installed, be not adversely affected. In other words, what was very definitely not wanted was a "Christmas tree" effect on the line.

f. It was essential that tower clearances, from a climbing and flashover standpoint, be not reduced any appreciable amount in order not adversely to affect in any manner, ease of regular line maintenance.

g. The tube installation itself, it was felt, in view of the newness of the device, would have to be not only accessible, but easily removable to take care of such maintenance as could not be eliminated except after years of experimental work and further development of the device.

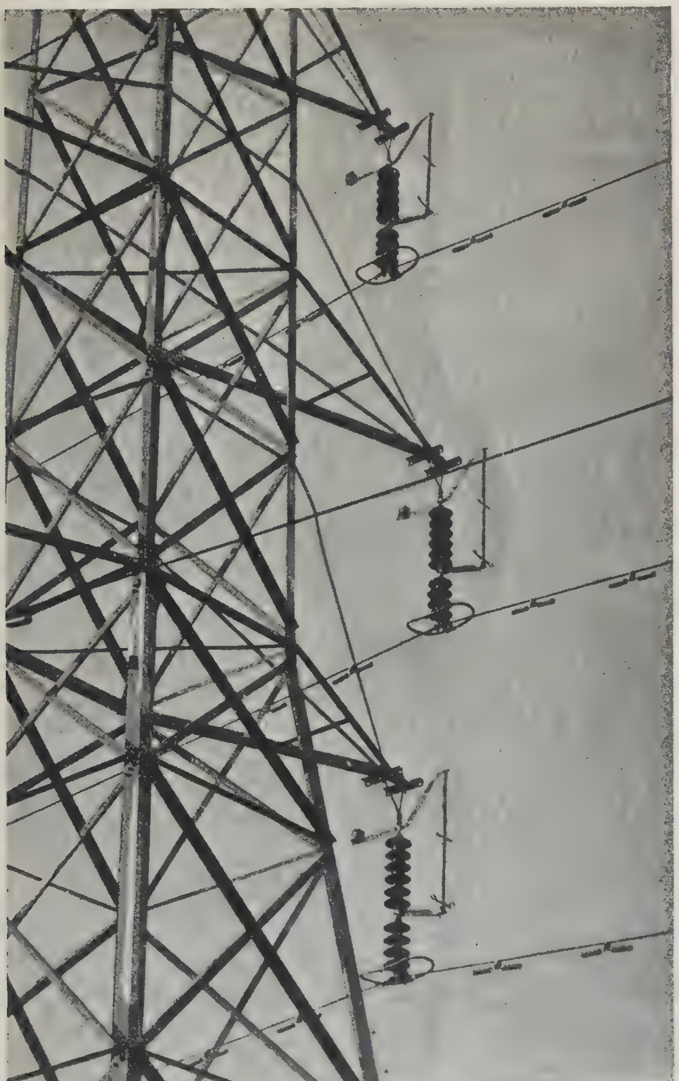

Fig. 2. Glenlyn-Roanoke tower showing all 3 phases of one 132 kv circuit equipped with expulsion protective gaps

Note the neat appearance and lack of tower cluttering shown in figure 1

Fig. 3. Parallel mounting. 132 kv expulsion protective gap mounted on suspension insulator string on Glenlyn-Roanoke line

Note flexible indicating targets in bottom tube vents, also adjustable external gap to ring

h. Finally, considering the present limited expansion in the utility industry, it was felt that if the device was to be of any appreciable service over the next 5 years or so, it would have to be fully adaptable to existing transmission line structures, and that very little benefit would be gained if the physical form of the device could be utilized only on new tower designs, and then only with difficulty.

Design Developments and Application

The expulsion protective gap (here called "the tube" for brevity) as applied to a 132 kv line, consists essentially of 2 "internal" gaps inside 2 fiber tubes. These 2 tubes in series are placed in series with an external gap, and the whole assembly connected from line wire to ground close to the insulation (here the insulator string) to be protected.

Tube Designs (*Physical*). The first design proposed for 132 kv steel tower service is the so-called 30 degree mounting (mounted about 30 degrees from the vertical) composed of a single mechanical assembly of 2 fiber tubes. This tube was designed to be fastened rigidly to the tower. The length of

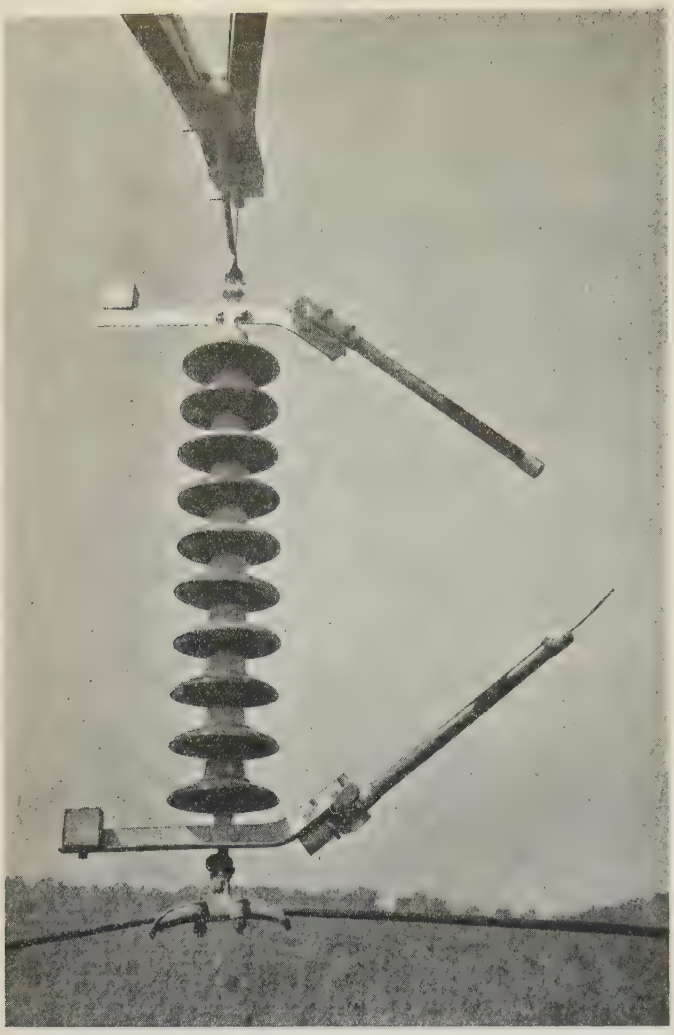

Fig. 4. "V" mounting. Expulsion protective gaps installed on single suspension insulator assembly on Glenlyn-Roanoke 132 kv line

this tube made it necessary to brace it to the tower at the middle point, as can be seen in figure 1. This rigid mounting to the tower made necessary the use of a curved top horn to maintain the external gap separation between the tube and conductor during conductor swing. The first developmental tests, subsequently referred to, were made on this design. However, after obtaining sufficient test data to indicate the probable successful operation of the device, it was realized that the 30 degree design failed to meet the fundamental requirements of *e*, *f*, and *g* enumerated above, and after considering a number of other possible designs, 2 were decided upon, each of which seemed to meet all the requirements as nearly as could be predicted; field installations of each of these designs were made to obtain operating experience.

Table I—Salient Line Characteristics

	Glenlyn-Roanoke	Roanoke-Danville
Number of circuits	2	1
Bottom conductor above ground	64 feet	64 feet
Conductor vertical spacing	13 feet	13 feet
Conductor horizontal spacing	21.8/26.8 feet	21.8/28 feet
Number of ground wires	1	1
Vertical height of ground wire above top cond.	10	10
Tower type	both 2 circuit steel, vertical configuration	
Number and spacing of insulators, single suspension	10—$4^3/_4$	10—$5^1/_8$
Impulse flashover (see ref. 4) (1 × 5 microsecond pos. wave) of suspension string	910 kv	1,050 kv
Same except ($1^1/_2$ × 40 microsecond pos. wave)	750 kv	865 kv

The first of these designs, the so-called parallel mounting, consisted of a tube assembly mounted parallel to and on the insulator string with the 2 tubes still assembled as one unit. An installation of this assembly on a single suspension insulator string is shown in figure 3 and a full tower installation is shown in figure 2. It will be noticed that very little new hardware was required in this assembly and that no previously existing clearances on the tower were in any way affected by the installation. The second of these designs is the so-called *V* mounting and is also mounted on the insulator string; it is shown in figure 4 for a single suspension assembly, in figure 5 for a double suspension assembly, and in figure 6 for a double dead-end assembly. Here the tube is broken up into 2 parts, with the gap at the center instead of at the end as in the case of the parallel and 30 degree assemblies.

Preliminary Tests of Tubes. After the possibilities of the tube were indicated by field experience of Pittman[6] in 1930 on a 110 kv line, some laboratory work was done in exploring the device in lower voltage fields. In the 132 kv field little had been done. Before the installation of the tubes on the lines of the American Gas and Electric Company, considerable experimental work was done to determine the electrical suitability of the device under the particular conditions imposed by this 132 kv system.

In September 1932, experimental tubes were tested[1] on this 132 kv system, and performed successfully. The above mentioned *V* and parallel assemblies having been decided upon after these initial field tests, further laboratory tests were made in March 1933 with tubes mounted on actual insulator assemblies to determine the tube protective features with impulse and 60 cycle voltages, under both wet and dry conditions. The tubes finally designed, as a result of the above tests, were again tested at Glenlyn on the 132 kv system in March 1933, with satisfactory results. In summary, these preliminary tests showed: That the tube was capable of interrupting the maximum 60 cycle current it was possible to obtain on test at the proposed location, namely, 6,700 amperes crest; and that the tube, by normal functioning, would protect the minimum line insulation consisting of a 10 unit insulator string of $4^3/_4$ inch units, under 60 cycle voltage wet and dry conditions, and also under the fast and slow positive impulse waves obtainable in the laboratory, likewise under wet and dry conditions. The few negative impulse tests made at the time did not indicate that the tube performance would be materially different under negative impulse voltages.

Field Installation of Tubes. One circuit of the Glenlyn-Roanoke 65 mile, 2 circuit line was equipped with tubes in 1933, the installation being completed July 1. Tubes were placed on each of the 3 phases at every tower of 1 circuit (number 1) only. The

installation of tubes on the Roanoke-Danville 68 mile, single circuit line (actually broken into 2 line sections—Roanoke-Fieldale and Fieldale-Danville) was completed on April 10, 1934. Here also tubes were installed on each phase at each tower. Some of the salient characteristics of both lines which have been presented before[5] are summarized in table I.

Types of Tube Mounting. The types of tube mounting—*V*, parallel, and 30 degree—used on these lines in the actual field installations are given in table II. Of the 1,713 assemblies, 54 were 30 degree assemblies merely to obtain some operating experience with this type, 831 were parallel assemblies, and 828 were *V* assemblies. In all cases *V* assemblies were used exclusively on double suspension and double dead-end insulator strings.

Fig. 6. Expulsion protective gaps on a dead-end assembly after external flashover

Note burned spots on tube where attached to tube fittings. The tube is still serviceable although showing burning of hardware and tube exterior finish

Operating Experience With Tubes

Procedure for Determining Tube Operation. After the installation of the expulsion protective gaps, close attention was given to their operation in service. On the Glenlyn-Roanoke line, surge crest ammeters[2] were installed on all tower structures, and on counterpoises, where used, to determine, in so far as possible, the character and severity of lightning conditions to which the line was subjected. Indicating targets over the vents of the tubes themselves gave information as to whether or not a tube had functioned in service. In addition, during the past lightning season, a crater lamp oscillograph[3] was in operation at the Roanoke station, and was connected to measure the 3 line currents in the Glenlyn-Roanoke number 1 tube-equipped line, 2 line currents in the Roanoke-Danville line, and the voltage from one phase to ground. This instrument, which is initiated in about 20 microseconds, in combination with the permanent magnetic oscillograph at Glenlyn (which initiates in about 0.5 cycle), and the other test and measuring facilities mentioned above, has given much valuable data on tube performance in service under lightning conditions. Periodic physical inspections of each tower made by climbing the tower also were made throughout the season.

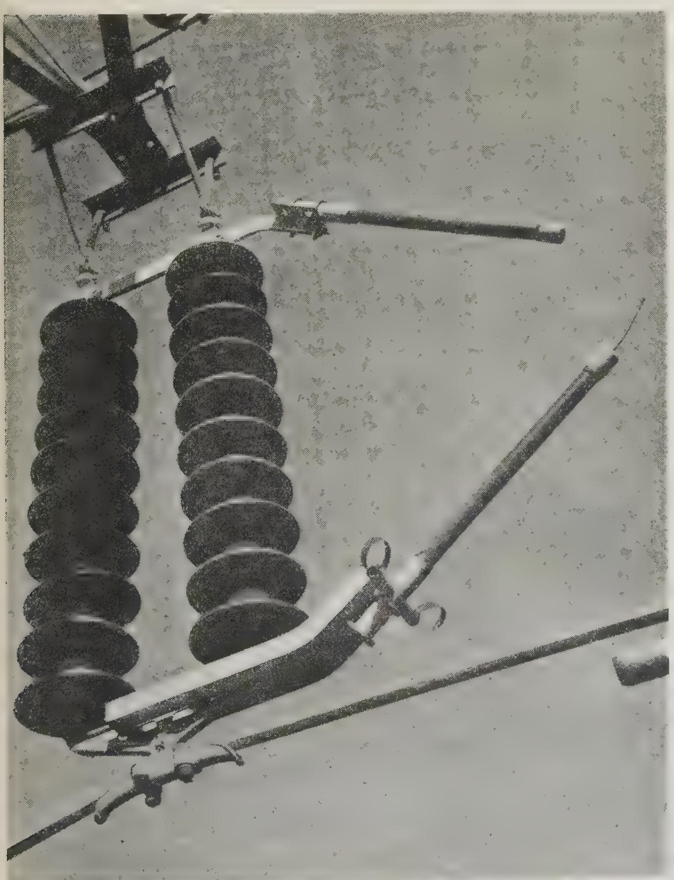

Fig. 5. "V" mounting. 132 kv expulsion protective gap assembly on double suspension insulator string on Glenlyn-Roanoke line

Tube Operations. The record of tube operations, as indicated by the targets over the vents, is given in table III. Targets indicated by reason of tower vibration, wind, or other extraneous causes have been excluded. A total of 262 normal tube operations was found, 246 of which occurred during 1934 when both lines were in service for practically the entire lightning season. During 1934, which was considered a heavy lightning year in the territory where these tubes were installed, approximately 15 per cent of the tubes were found to have functioned once. In only 5 cases were tubes found by targets to have functioned twice during the year, and none more than twice. Based on the 1934 record of both lines, the tube operations found by targets averaged 1.85 per mile of line per year, and were observed on 28 per cent of the towers.

External tube arc-over was found on 17 tubes,

Table II—Types of Tube Mounting Used on 132 Kv Lines

	Glenlyn-Roanoke	Roanoke Danville	Total
30 degrees to vertical—single suspension	54	0	54
V—dead end	249	150	399
V—single suspension	48	234	282
V—double suspension	78	69	147
Parallel—single suspension	381	450	831
Total assemblies	810	903	1,713

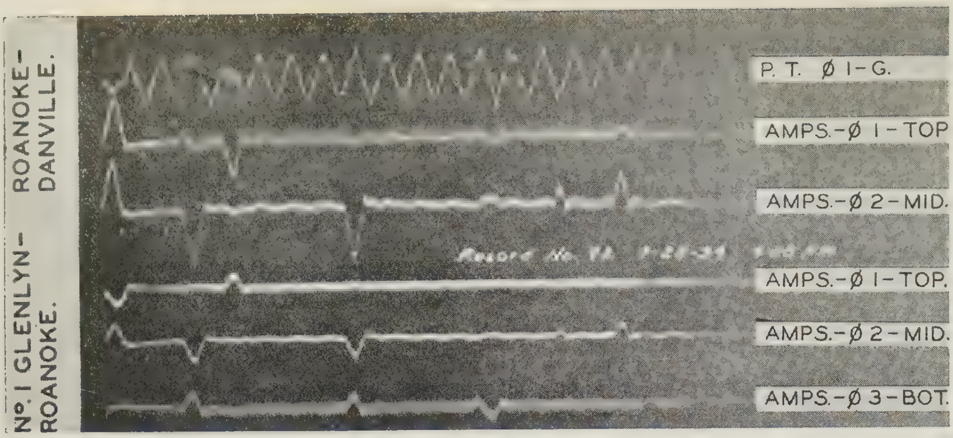

Fig. 7. 132 kv expulsion protective gap operations during multiple lightning stroke on Roanoke-Danville line

11 tube discharges resulted from 8 repeated strokes occurring within 26.5 cycles

Tube discharges from last stroke not shown in this part of record

Crater lamp oscillograph record number 73

Recorded at Roanoke

which is 1 per cent of the tubes in service, and 7 per cent of the tube operations indicated by target. These arc-overs involved 14 towers and are believed to have caused 12 line tripouts, 9 on the Glenlyn-Roanoke line and 3 on the Roanoke-Danville line. The reason for these external tube flashovers has not as yet been fully explained, although in one case at least it is known that a tube flashover took place under rain conditions far more severe than any generally accepted wet test prescribed by A.I.E.E. standards. It is hoped that the study now being carried on to improve the impulse flashover characteristics of the tube will completely overcome this difficulty, the absence of which would probably have resulted in a 100 per cent lightning-proof line on these 2 trial lines during their first complete year of tube operation.

Power Current Interrupted by Tubes. A determination of the actual power current interrupted by the tubes in service was attempted by analysis of the oscillograph records. The maximum estimated currents which any tube was called upon to interrupt are given in the third column of table IV. Of some 120 current records obtained on the crater lamp oscillograph, the above are typical and include those of highest magnitude observed. Since interpretation of the data requires not only coincident oscillograph records at both ends of the line, but also a knowledge of the location on the line where a tube has operated, whether more than one tube on a given phase has operated, and other detailed information, an exact statement of actual currents interrupted is impossible. From the records available, however, it appears the tubes have successfully interrupted power currents as high as 3,500 amperes crest (2,500 amperes root mean square) which is 25 per cent in excess of the rating of the affected tube, assuming a single tube interrupted this current. This record is interesting in view of the fact that no tube has failed mechanically due to its inability to interrupt the current it has been so far called upon to handle.

Multiple Lightning Strokes. Although a detailed discussion of the theory of multiple lightning strokes is outside the scope of this paper, some data along this line have been obtained in the investigation of the performance of the expulsion protective gaps during the past year which have considerable bearing upon judgment of the tube performance. Some of the oscillograph records obtained indicate multiple strokes varying in number from 2 to 8, within a period of 2 to 26.5 cycles. These records are summarized in the last 4 columns of table IV. The record of 8 separate strokes obtained on the crater lamp oscillograph at the Roanoke end of the line during one lightning disturbance is shown in figure 7. The simultaneous record, not shown, on the magnetic oscillograph at Glenlyn indicated that the eighth lightning stroke occurred 26.5 cycles after the first stroke. While the records show as many as 8 discharges, it is, of course, not certain that any one tube is subjected to all the discharges, in some cases the tube passing current being on a different phase, or phases, at successive strokes. Again, it must be remembered that it is impossible to conclude definitely from the records obtained whether or not the stroke initially contracted the line at or near one tower and finally ceased at or near another tower. This might be possible within a period of 26.5 cycles. At any rate, such multiple strokes indicate that a given tube may actually be functioning a greater number of times than will be shown by the target indication on the tube. This point should be kept in mind when considering the limitation of tube life from internal erosion.

Another interesting record of a multiple stroke

Table III—Tube Operations in Service

By Target Indication

	Number of Tube Operations		
	Glenlyn-Roanoke[1]	Roanoke-Danville[2]	Total
1933			
30 degree tower mounting	0		0
V mounting	14		14
Parallel mounting	2		2
Total, 1933	16		16
1934			
30 degree tower mounting	0		0
V mounting	51	55	106
Parallel mounting	39	101	140
Total, 1934	90	156	246
Towers affected	56	104	160
Tubes externally arced over	12	5	17
Towers with external arced-over tubes	11	3	14
Total towers on line	270	300	570

1. Tubes on this line in service July 1, 1933.
2. Tubes on this line in service April 10, 1934.

which produced an outage of the tube equipped Glenlyn-Roanoke line is shown in figure 8. This record was obtained on the magnetic oscillograph, and therefore fails to show the power current at the start of the stroke. However, 3 separate strokes are clearly shown, occurring from 3 to 10 cycles after the first stroke which apparently initiated the oscillograph. On the occurrence of the second stroke, phases 1 and 2 of the number 1 tube equipped line faulted to ground, the tube clearing the fault on phase 1 in a half cycle, but the fault on phase 2 developed into a short circuit which was finally cleared by the line circuit breakers. However, before the circuit breakers opened, a third stroke took place to phase 1, which was cleared by the tube, and after another 4 cycles, the fourth stroke faulted phases 1 and 3, clearing on phase 3 but developing into a short circuit on phase 1. This record shows the type of service to which a tube may be subjected in service and indicates that actual tube operations may considerably exceed those indicated by targets.

Lightning Currents in Tube and Stroke. A knowledge of the actual current conditions imposed on a tube in service is important in determining whether or not the tube is performing as expected, and also serves as a basis for determining its performance limits. It is known that if an impulse current of sufficient magnitude is passed through a tube, the tube will fail mechanically without the presence of 60 cycle follow current. To determine the range of lightning currents which the above tubes probably handled—and from the records passed successfully—a group of lightning currents obtained on tower legs by surge crest ammeter readings has been analyzed as shown in table V.

In this analysis, only tower currents above 25,000 amperes have been taken, and it has been assumed that these currents are the result of direct strokes to the tower top or to the ground wire close to the tower. The stroke current is assumed to travel to the tower where it seeks various paths, over the insulator strings to line conductors—where tube operations were indicated—through the tower to ground, and continuing along the ground wire, all according to the laws of traveling waves.

Table IV—Power Current Interrupted by Tubes, and Multiple Lightning Stroke Characteristics

From Crater Lamp Oscillograph Record

	60 Cycle Crest Amps.		Multiple Stroke Record			
Ref. No.	Measured at Roanoke	Estimated through Tube	Successive Strokes	Max. No. per Tube[1]	Cycles First to Last Discharge	Cycles Between Strokes
23	850	3,500	2	1	9	9
40	1,150	1,500	2	2	9	9
43	1,550	2,000	2	2	2	2
48	1,130	1,500	4	3	12 1/2	2 to 7 1/2
49	1,900	2,500	2	2	3	3
51	2,600	3,000	2	2	2 1/2	2 1/2
57	1,650	2,000	3	2	9	2, 6
72	1,720	2,000	2	2	3	3
73	2,100	2,500	8	6	26 1/2	1 1/4 to 9 1/2
80	600	750	3	3	20	3, 16

1. Assuming one tube interrupted all currents indicated by the oscillograph on a given line conductor.
No tube failures or line trip-out during above tube operations.

Table V—Lightning Currents Through Tubes and in Lightning Strokes

Calculated From Field Records of Lightning Currents in Tower Legs

		Crest Amperes			Tube Operations	
			Calculated[1] in			
Ref. No.	Tower Foot Resist. (Ohms)	Measured in Tower Legs	Each Tube	Lightning Stroke	Location (Top, Mid., Bot.)	Successful or Not
2	85	−28,000	11,000	38,000	TM-	Yes
7	24.5	−29,000	12,000	33,000	--B	Yes
8	11.0	−38,000	15,000	45,000	-M-	Yes
10	35.0	−30,000	12,000	40,000	-MB	Yes
11	39.5	−26,000	12,000	40,000	TMB	Yes
14	10.0	−64,000	25,000	86,000	TM-	Yes
24	28.5	+28,000	11,000	32,000	-M-	Yes
25	14.0	+64,000	29,000	100,000	TMB	Yes
26	14.0	−38,000	17,000	59,000	TMB	Yes
28	27.5	+29,000	12,000	39,000	TM-	Yes
33	6.5	−40,000	16,000	54,000	-MB	Yes
35	12.5	−83,000	37,000	130,000	TMB	Mid. flashover
40	8.0	−52,000	23,000	80,000	TMB	Mid. flashover
43	12.3	−57,000	26,000	88,000	TMB	Yes
45	41.5	−30,000	12,000	35,000	T--	Yes
52	16	−34,000	15,000	53,000	TMB	M. & B. flashover

1. Based upon traveling wave theory.

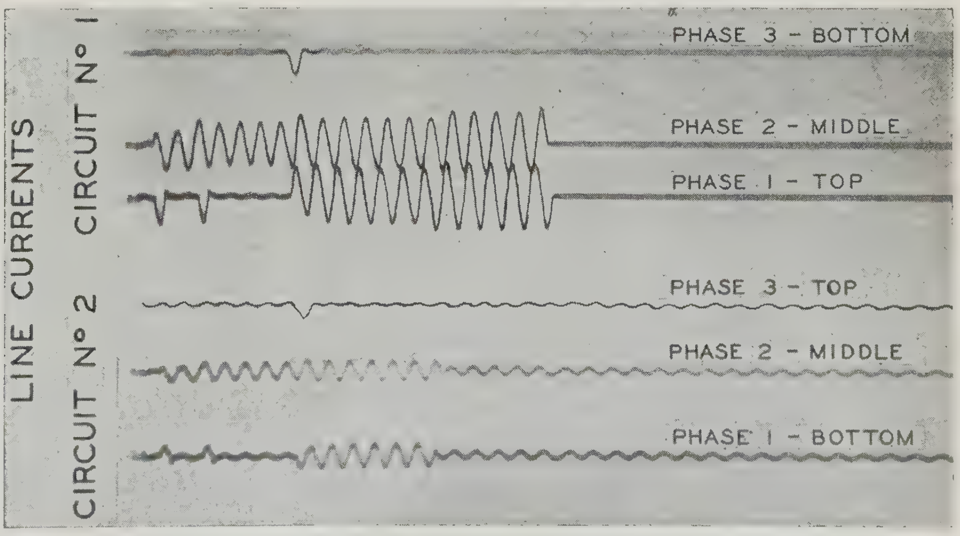

Fig. 8. Single circuit outage due to lightning

Glenlyn-Roanoke 132 kv double circuit line, June 26, 1934, 3:35 p.m. Automatic oscillograph record number 888. Recorded at Glenlyn plant

The results of this analysis (table V) indicate that an individual tube may have passed as high as 37,000 amperes of lightning current; and the probable stroke current was as high as 130,000 amperes.

While the type of data available does not warrant precision calculations, general considerations of lightning wave shapes and points of inception on the line permit the conclusions that the tube currents may be only about $^1/_2$ the values given, and the stroke current some 60 per cent above the values given in table V. The general order of currents involved in the stroke itself, therefore, is in agreement with more recent theory and with more recently reported field results.

Table VI—Outages Caused by Lightning; Glenlyn-Roanoke and Roanoke-Danville Lines

Year	Glenlyn-Roanoke				Roanoke-[1,5] Fieldale	Fieldale-[1,5] Danville
	No. 1[5]	No. 2	Nos. 1 and 2	Total		
1926	6	6	4	16	...	...
1927	13	8	3	24	9.5	7.9
1928	2	3	2	7	7.6	6.3
1929	13	6	10	29	12.1	10.1
1930	5	1	5	11	17.5	14.5
1931	7	8	15	30	13.7	11.3
1932	2	2	2	6	4.5	3.8
1933	1[2]	3	2[2]	6	9.7	8.1
1934[3]	8	7	1	16	1	2[4]

1. Prorated for these line sections from 1926 to 1933 when part of Roanoke-Roxboro line.
2. These occurred before tubes were installed on number 1 line.
3. Record to October 15. Tubes on all 3 lines.
4. Three additional trip-outs apparently caused by trouble on 33 kv side of power transformer.
5. Expulsion protective gaps on this line during part of 1933 lightning season and all of 1934.

Line Outages. As the main purpose of the tubes is to prevent line flashovers and resulting outages, the operating record of the 2 lines is perhaps the most pertinent factor. This is given in table VI. Since the Roanoke-Fieldale and Fieldale-Danville lines were originally a continuous part of the Roanoke-Roxboro 98 mile line, the outage records from 1927 to 1933 have been prorated on a length of line basis. While this procedure is open to criticism, it is practically the only way in which the relative performance of the Roanoke-Danville line can be compared before and after the tubes were installed. Line outages on the tube equipped (number 1) Glenlyn-Roanoke line in 1933 were eliminated, as were also the double circuit outages. Previous to 1933, the single circuit outages on this line averaged 6.8 yearly, and the double circuit outages 6 yearly. In 1934, the corresponding single circuit outages were 8 and the double circuit outages 1. All outages on the tube equipped line this year, 1934, have been attributed to external flashover of the tube under lightning conditions, a situation which it is believed possible to improve vastly, and probably to eliminate, by alterations in the tube design. On the number 2 line, not equipped with tubes, there were 7 single circuit outages against an 8 year average of 4.6 previously.

On the Roanoke-Fieldale line there was one outage in 1934 against a 7 year previous average of 10.6; and on the Fieldale-Danville line there were 2 outages in 1934, against a 7 year previous average of 9.0. Here again, the 3 outages this year were attributed to external flashovers of tubes under lightning conditions.

Thus it is seen that while the expulsion protective gap, in its present stage of development for use on 132 kv lines, has not rendered the line lightning-proof, it has very materially reduced service outages without deleterious effects on the system as a whole, or on any part of the line itself.

Tube Maintenance. The maintenance work so far done on the tubes installed consists of a complete repainting of all tubes on the Glenlyn-Roanoke line after about one year's operation. Since the performance of fiber subjected to voltage stresses and leakage currents of the order existing on the tubes as actually installed is not known, it was considered desirable to recoat the exposed surface of the fiber. The exterior finish of the Roanoke-Danville tubes, which is an improvement over the Glenlyn-Roanoke tubes, has not as yet shown sufficient deterioration to consider refinishing. More experience is needed to determine the maintenance problems which will be encountered during the life of the tubes.

Summary and Conclusions

From the record presented and other data not given here, the following features of the expulsion protective gap and its application to 132 kv lines are outstanding:

1. The expulsion protective gap appears to be an effective device for preventing lightning flashover of a line and reducing line outage.

2. In service it has successfully interrupted power currents within its rating, without any signs of weakness or distress. In practically every case, where records were obtained, it has interrupted the power current in one cycle or less.

3. A practical method of applying the tube to vertically configurated 2 circuit lines has been worked out which avoids cluttering up the tower structure, and still maintains normal clearances.

4. The present design of tube can be applied to existing high voltage steel tower lines without structural or insulation changes, unless the present line insulation is abnormally low.

5. In its present form and state of development, the tube will doubtless require some maintenance to keep it in the best operating condition. The weathering qualities of the tube are still unknown and may have to be improved.

6. The impulse flashover characteristics of the tube must be improved if it is to render a line lightning-proof. This improvement seems at present feasible, although it may require considerably more data on the characteristics of natural lightning before it is fully attained.

7. Close watch on the tube performance in the field, combined with a detailed study of lightning conditions under which the tubes operate, will doubtless result in more rapid development of the tube as a practical device for mitigation of lightning troubles on lines and equipment.

8. Multiple lightning strokes may have to be considered in estimating the expected life of the tube; as many as 8 successive discharges were recorded in one stroke within a period of 26.5 cycles. Only 2 per cent (5) of the tubes which functioned, as evidenced by the targets, operated on more than one occasion (multiple strokes not included).

9. Tubes have successfully discharged lightning currents, according to calculations based upon field data, of an order as high as 37,000 amperes. Lightning stroke currents in the order of 200,000 amperes have been indicated.

10. The lightning outage record of the 2 lines equipped with expulsion protective gaps has shown a vast over-all improvement; there were no 2-circuit outages on one line in 1933, and only one in 1934.

11. Although the tubes have not given 100 per cent perfect performance in their first full year of operation they have really performed as well as was expected. It is believed that, considering their present trial stage of development, they have, on the whole, performed creditably.

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Transient Voltages on Bonded Cable Sheaths

Field experience and tests show that unexpectedly high transient sheath voltages occur during the switching of charging current in single-conductor cable-type bus leads and in underground single-conductor power transmission cables bonded to eliminate sheath losses. No sheath troubles from these voltages have been found. Theoretical analysis of these voltages is presented together with suggested methods for protection of equipment, when the latter is necessary.

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In order to eliminate sheath losses on single-conductor lead-sheathed cables on 3 phase circuits, it is common practice to interrupt the continuity of the metallic sheath at intervals by the use of sheath insulators and to bond the sheaths in a variety of ways.[1] This procedure results, first, in reduction of cable size or installation cost, and second, in reduction in operating line losses or charges. Several years of successful operation in Chicago and elsewhere with Kirke-Searing cross-bonding, or H & M series transformer bonding, or other types of bonding, failed to reveal any evidence of transient voltages appearing on the sheaths, or any harm therefrom. Although theoretical considerations had indicated the possibility of such transient sheath voltages, no operating experience had shown the need for an investigation. The existence of such voltages was first indicated by the flashover of sheath insulators on 3,000,000-circular-mil lead-covered armored cable used as part of the metal clad switching bus at the Waukegan station of the Public Service Company of Northern Illinois during switching, and later by the failure in service of a few sheath-bonding transformers, which had less insulation than transformers previously used elsewhere, on one 66 kv line of the Commonwealth Edison Company, Chicago. Field tests were made at both locations to determine the cause and nature of such transients, and how to render them innocuous. F. O. Wollaston of the Commonwealth Edison Company was of considerable assistance in the preparation of the paper.

In the tests made in Chicago on 66 kv lines and at Waukegan station on the 132 kv switchgear, it should be noted that the data are incomplete and very rough because (*a*) the voltages were random; (*b*) measurements were made with roughly approximate devices; and (*c*) little data were obtained on conductor surges. For these reasons and because field conditions are too complex for any but a qualitative theoretical analysis, the following conclusions must be considered as tentative:

1. Surge voltages as high as about 30 kv across insulators or about 15 kv to ground may be produced on underground cable sheaths by the switching of charging current, particularly on deënergizing the line. Sheath voltages are highest near the switching end of the line. They are substantially less at distances of a few thousand feet from the switching end, and are negligible at the far end of the line. On short cables forming part of switching structures the sheath voltages may be considerably higher.

2. High transient sheath voltages can be caused by either traveling waves or oscillations on the cable conductor. Both are usually present, the disturbance starting as a traveling wave on the conductor but quickly changing to a damped oscillation. The latter contains most of the surge energy since it may last several hundred microseconds and is fed constantly by the switching arc.

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1. For all numbered references see list at end of paper.

3. Oscilloscope data obtained 1 mile from the switching end of one line showed that about 90 per cent of the sheath surges were oscillatory; the surge recorders, many of which were near the switching end, on several lines showed that nearly half of the surges were unidirectional or highly damped oscillations.

4. Field experience and tests indicate: (*a*) that these potentials do *no* harm to cable sheaths or sheath insulators; and (*b*) that where necessary for equipment, they may be reduced to harmless proportions by the use of simple protective devices or adequate insulation may be provided to withstand them at little expense.

5. Voltages at any given point for a particular type of bonding are dependent to a large extent on the bonding connections existing elsewhere on the line.

6. Because of the diversity of bonding connections and the physical differences in the several lines tested, the measured sheath voltages for the different types of bonding are not directly comparable.

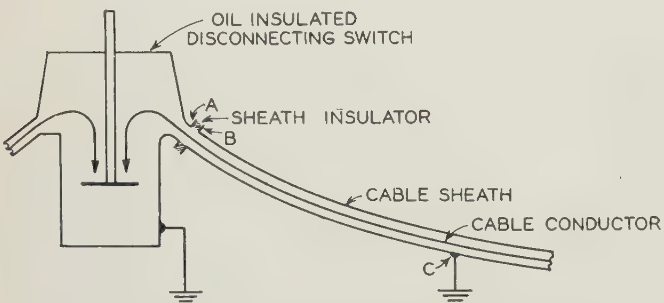


Fig. 1. Diagram showing conditions at Waukegan station bus; cable lengths were 30 to 85 feet

However, if the normal bonding connections are opened at 1 or 2 points on a line, then the transient sheath voltages may increase a few-fold at such points.

7. During switching of underground lines damped oscillations were observed having the following characteristics on the conductors and sheaths: (*a*) frequencies from 2,000 to 80,000 cycles per second, i. e., from 1 to 17 times the resonant frequencies of the conductors involved; (*b*) durations of from 100 to more than 800 microseconds; (*c*) maximum voltages on the conductors up to 3 times normal 60 cycle crest; and (*d*) associated calculated maximum conductor currents of 2,000 to 6,000 amperes.

8. Theoretical analysis indicates that transient sheath voltages resulting from conductor voltage oscillations would tend to increase as the line operating voltage increases and as the line length decreases, other conditions being equal.

9. Possible damage to equipment from sheath surges may be prevented by the following methods: (*a*) For high tension cable having lengths of a few hundred feet or less, shunt capacitors of 10 microfarads or more may be connected across sheath insulators; (*b*) for underground lines it appears preferable to provide adequate insulation for the insulators, the gaps in the sheath inside the insulators, and the bonding equipment to withstand transient sheath voltages. Protective shunts or arresters, if used, should be connected between sheath and ground.

10. No tests were made with impressed traveling waves known to be essentially unidirectional, so that no information was obtained as to the sheath voltages that might result from lightning surges entering cables with specially bonded sheaths.

Table I—Effect of Shunting Sheath Insulator at Waukegan Station

Switch Used: Oil Breaker	Switch Used: Oil Disc.	Shunt Across Insulator	Maximum Volts Across Insulator	Measured by
x		None	30,000	Flashover
	x	None	30,000	Flashover
x		1/2 ohm res.	<1,000	Surge recorder (Lichtenberg figure type)
	x	1/2 ohm res.	16,000	Surge recorder (Lichtenberg figure type)
x		1 ohm res.	<1,000	Surge recorder (Lichtenberg figure type)
	x	1 ohm res.	12,000	Surge recorder (Lichtenberg figure type)
x		14 μf	<45	Glow lamp
	x	14 μf	<45	Glow lamp
x		1 ohm & 14 μf	<45	Glow lamp
	x	1 ohm & 14 μf	<45	Glow lamp

Field Investigation on Waukegan Station Bus

The essential conditions encountered on the Waukegan Station bus are shown in figure 1. The circuit was interrupted either by an oil circuit breaker or by an oil insulated disconnecting switch. Inspections had shown that visual flashovers usually occurred only with the operation of the disconnecting switch. The distance from B to C along the cable was about 15 feet, while the distance from A to B around through the grounds and ground bus was about 45 feet. The flashover distance over the insulators was about $1^1/_4$ inches. The effect of bridging the sheath insulators with resistors or capacitors or both in parallel is shown in table I. In these tests, only charging current was interrupted, because the interruption of load currents had caused no high sheath voltages.

Tests with a magnetic type of oscillograph in the sheath circuit gave no voltage indications, showing that the transients were too short or the oscillation of too high a frequency to be measured. The resistors, when bridging the gap alone, became red hot.

Field Investigation on 66 Kv Lines in Chicago

The existence of high sheath voltages on specially bonded 66-kv lines in Chicago was indicated when internal short circuits were found in a few bonding transformers. Since the lines have no overhead con-

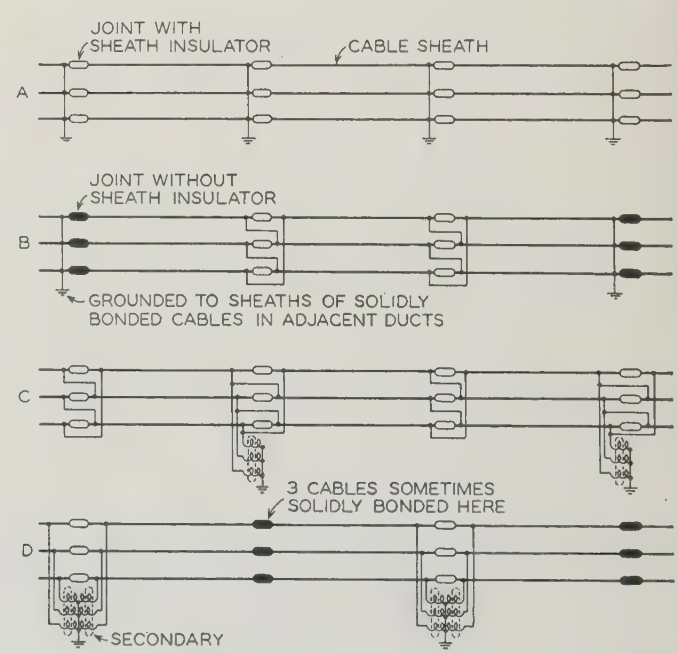


Fig. 2. Methods of bonding single conductor cables

A. One-end bonding. B. Kirke-Searing cross-bonding C. Star bonding. D. H & M series transformer bonding

Table II—Surge Voltages Measured on Cable Sheaths of 66 Kv Line 6341 at 32d Street and Hamlin Avenue

Test location 3,480 feet from Crawford station. Adjacent bonding transformers were 1,000 and 992 feet toward Crawford and Northwest stations, respectively. Switching at Crawford end of line with Northwest end open (except in test 3). Line is H & M series transformer bonded throughout except for 2 Kirke-Searing cross-bonded sections adjacent to Crawford station and 1 one-end bonded length adjacent to Northwest Station

	Test Conditions in Manhole					Surge Voltage Recorder Data, Highest Voltage Recorded in Kilovolts Crest*									Range of Approximate Data Obtained by Cathode Ray Oscilloscope Connected From *B*-Phase Sheath to Ground on Crawford Side			
				Capacitance, Microfarads		Northwest Side			Across Insulator			Crawford Side				Duration, Microseconds		
Test No.	No. of Switching Cycles	Series Transformer Connected	Resistance, Ohms Sheath to Grd.	Sheath to Grd.	Across Insulator	A φ Grd.	B φ Grd.	C φ Grd.	A φ	B φ	C φ	A φ Grd.	B φ Grd.	C φ Grd.	Kilovolts Crest	Front	Entire Surge	Frequency, Kilocycles
1	3	No	None	None	None	6.3	9.3	7.6	17.8	15.4	12.7	7.2	8.4	7.2				
2	2	No	None	None	None	7.2	8.9	8.0	...	...	12.7	...	...	...				
3	1‡	Yes	None	None	None	...	...	...	...	...	...	...	...	...	0	—	—	—
4	3	Yes	None	None	None	—	6.3	—	3.0	12.7	—	—	8.0	—				
5†	2	Yes	None	None	None	—	—	—	2.6	6.8	—	T	8.9	—	$\frac{3}{4}$–3	20–190	100–750	Unidir.-20
6†	2	Yes	None	None	None	4.0	—	7.2	8.9	—	11.2	4.9	—	6.8	0–1$\frac{3}{4}$	100–200	500–650	2
7	2	No	33	None	None	5.3	4.4	5.6	14.2		14.2	4.9	5.6	5.3				
8	2	No	None	2.0	None	3.7	2.5	2.6	7.2		9.3	2.6	—	2.8				
9†	2	No	None	4.0	4.0	—	—	T	—		T	T	—	T				
10	3	Yes	17	None	None	—	—	—	2.8		—	—	2.6	—				
11	4	Yes	33	None	None	—	—	—	3.3		—	—	4.4	—				
12**	1	Yes	33	None	None	—	—	—	4.9		—	—	2.8	—				
13	3	Yes	None	2.0	None	—	—		2.6		—	—	2.5	—				
14	1	Yes	None	None	4.6	T	T	T	—	—	T	—	T	T	1	20	250	13
15†	2	Yes	None	None	6.9	—	—	—	—	2.6	—	T	T	—	1$\frac{1}{4}$–2	10–150	450–550	3–6
16	1	Yes	None	None,	9.2	T	—	T	T	2.6	T	T	T	T	1$\frac{3}{4}$–2$\frac{1}{2}$	50	200–250	4.5–11
17	1	Yes	None	2.3	2.3	T	T	T	T	2.5	T	T	2.5	T	1$\frac{1}{2}$–3	50–60	200–400	5.7–6
18†	3	Yes	None	4.0	4.0	T	—	T	T		—	T	—	T				
19**†	2	Yes	None	4.0	4.0	T	—	T	T		T	—	T	T				
20	1	Yes	None	4.6	4.6	—	—	T	—	—	—	T	T	—	$\frac{1}{2}$–3	30–40	200–350	Unidir.-10
21†	2	Yes	None	4.6	4.6	—	—	—	—	2.5	—	—	T	—	1$\frac{1}{2}$–3	40–50	350–600	4–8
22†	2	Yes	None	4.6	4.6	—	—	—	2.5	—	2.5	—	—	—	0–$\frac{1}{4}$	40–50	500	3–23

* Where more than one surge was recorded on the same set of films, only the highest voltage is shown here. The letter "T" indicates a trace, less than 2.5 kv; a dash, no indication on film; and blank, no recording device connected.

** In tests 12 and 19, the 3 cable sheaths were bonded solidly together and to ground at a point 300 feet from the test location toward the Crawford end of the line.

† In these tests, observers heard audible discharges at each switching operation, indicating that external flashovers may have held some of the voltages to lower values than otherwise would have been the case.

‡ Switching small load.

nections except at the terminal bus structures, the possibility of these failures being caused by lightning was considered negligible. Examination of the transformers disclosed that there had been failures through layer insulation between approximately the end of the winding connected to the cable sheath and the end connected to ground. The puncture path was bridged with pitted and melted copper, short-circuiting the winding. The transformers that failed were of a relatively small lot of new design with less insulation than the much larger number of transformers that had operated successfully. All transformers were built to operate at a normal potential of 12 volts to ground.

Line 6341. The failures of the bonding transformers occurred on line 6341 between Crawford and Northwest Stations. The bonding is of the H & M series transformer type (see figure 2) except that one-end bonding is used for the Northwest terminal length and 2 complete sections of Kirke-Searing cross-bonding are adjacent to the Crawford terminal.

In the tests, the oil switch was opened and closed with the line open at the far end, except for a few such cycles of switching with load on the line. The sheath voltages were measured at a few locations by surge voltage recorders, supplemented by a cathode ray oscilloscope and neon glow lamps calibrated for surge voltages. The oscilloscope figures were watched by several observers, immediately drawn from memory by each man, compared, and a final figure agreed upon. Surprisingly good agreement was found between observers on the various characteristics of the figures.

Each glow lamp was coupled with a resistance voltage divider so that the lamp would glow when the applied voltage exceeded a certain definite minimum. A bank of lamps connected in parallel was used for each measurement each lamp being calibrated to glow at a different surge voltage. The approximate magnitude of voltage was indicated by the calibration of the lamps that glowed, if any. The surge voltage recorders were of the stationary film type used in the lightning investigation work in Chicago.[2] Each device contained 2 films for recording the direct and reverse polarity Lichtenberg figures of a unidirectional surge, combination figures being obtained for oscillatory surges.

Data are shown in table II for only one test location, but with different sheath connections and various protective apparatus. Data obtained at other locations on the Crawford half of the line during these tests were essentially similar.

Before attempting to draw comparisons between different connections and types of protection, it should be mentioned that the series bonding connections adjacent to the test locations in both directions were left undisturbed throughout the tests. For the open-end bonding tests 1 and 2 and also for tests 4, 5, and 6 of table II, as well as similar tests mentioned but not tabulated, the remote end of the sheath may not be considered as solidly grounded either in response to applied traveling waves or os-

Table III—Tests on 66 Kv Line 6313, Crawford Station to Fisk Street Station

Length of line 27,960 feet. Line is Kirke-Searing cross-bonded throughout except for 3 tunnel lengths at scattered locations having solid bonding. The 2 test locations were at the manholes with cross-bonding nearest the Crawford station end of 2 Kirke-Searing cross-bonded sections. The original bonding was not disturbed for these tests

			Voltages (Kv) Indicated by Surge Voltage Recorders and Glow Lamps†											
			Manhole No. 841, 170 Ft From Crawford Terminal (Lengths in Section Were 170, 366, and 146 Ft)						38th Street and Spaulding Ave., 5,280 Ft From Crawford (Lengths in Section Were 338, 338, and 366 Ft)					
			Crawford Side		Across Insulator		Fisk Side		Crawford Side		Across Insulators		Fisk Side	
Test No.	Switching Location	No. of Switching Cycles*	A φ Grd.	C φ Grd.	A φ	C φ	A φ Grd.	C φ Grd.	A φ Grd.	C φ Grd.	A φ	C φ	A φ Grd.	C φ Grd.
1	Crawford	3	6.8 (2) 6.0	8.0 (2) 12.0	22.0 15.4	18.2 25.0	7.2 10.4	8.9 8.0	3.3(2) 2.5	2.6 (2) 2.6	6.3 2.7	4.0 7.2	2.6 2.8	2.6 2.6
2	Crawford	3	8.0 (2) 6.8	8.0 (2) 8.9	19.7 20.4	12.3 20.4	8.9 7.2	7.2 8.0	2.7 (2) 2.8	2.5 (2) 2.6	4.0 5.3	3.3 4.0	2.5 2.6	2.6 3.3
3	Fisk	3	— (—) —	— (—) —	— —	— —	— —	— —	— (1) —	— (1) —	— —	— —	— —	— —
4	Fisk	3	— (—) —	— (—) —	— —	— —	— —	— —	— (—) —	— (0.5) —	— —	— —	— —	— —
5	Fisk	2			— (—) —	— (—) —					— (1) —	— (1) —		

* Switching charging current only.
† Top figure represents voltage indicated by line side film; bottom figure is voltage indicated by ground side film. A dash indicates that no record was obtained; a blank, no recording device connected. Glow lamp voltages, shown in parentheses, are minimum surge voltages necessary to cause lamp to glow; in these tests the range of voltage that could be indicated was 0.5 to 2 kv.

cillations because of inductance and unknown "carry-over" voltage in the half coil induced from the other 5 half coils on the same core.

The test results must be accepted with caution because of the random nature of the voltages produced by the switching arcs, large inconsistencies in some of the data, probable reduction of some of the voltages by flashover (which voltages otherwise would appear with larger values in the tabulation), and the very rough methods used for measurements. Examples of inconsistencies are: (*a*) where the voltages across the insulators in tests 1, 7, and 8 exceed by a large percentage the sum of the voltages to ground on both sides—an impossible result; and (*b*) in test 5 where the surge recorder and oscilloscope data disagree greatly.

Complications such as unsymmetrical cable spacing, the position and nature of other cables in the conduit, the presence of sheet iron bands around the ducts, and the degree of wetness of the ducts and especially of the fireproofing material covering the insulators, have all been ignored. Similar remarks apply to data recorded in other tables and test results cited.

Subject to these limitations, table II presents several points of interest. A comparison of test 3 with other tests indicated that negligible sheath voltages appeared when switching was done with the line closed to the power transformer at the far end, whereas appreciable voltages generally appeared when switching charging current only. Table II also indicates that the highest voltages appeared when the series bonding transformer connections were open at the test location. With the transformer connected, the average voltages to ground and across insulators were reduced by about $^1/_2$ and $^2/_3$, respectively, although maximum voltages were decreased to a much lesser extent. In similar tests at other locations, not tabulated, the reduction of average and maximum voltages was more pro-

Table IV—Tests on 66 Kv Line 6342, Crawford Station to Northwest Station

Length of line is 55,600 feet. Line is star bonded throughout, except for 5 Kirke-Searing cross-bonded sections at scattered locations, 3 of which are adjacent to each other. The test section is the middle 1 of the 3 sections, and consists of 470, 473, and 395 foot lengths. Measurements of voltage were made at locations normally having cross-bonding

		Voltages (Kv) Indicated by Surge Voltage Recorders and Glow Lamps†										
		Elston and Warsaw Avenues (3,680 Feet From Northwest Station)								Elston and Wellington Avenues (4,150 Feet From Northwest Station)			
			Northwest Side		Across Insulators			Crawford Side			N.W. Side		
Test No.	No. of Switching Cycles*	Sheath Bonding Connections	B φ Grd.	C φ Grd.	A φ	B φ	C φ	A φ Grd.	B φ Grd.	Sheath Bonding Connections	A φ Grd.	B φ Grd.	Across Insulator of B φ
1	2	Open	2.7 (1)	7.2	6.3	6.8	12.7	2.7	3.3	Normal	2.6	—	—
2	1	Open	3.3 (2)	7.2	7.2	8.0	29.0	3.0	3.7	Normal	2.8	—	—
3	2	Normal	— (0.5)	—	—	2.5	—	—	—	Normal	—	—	—
4	2	Normal	— (0.5)	—	2.5	—	—	—	—	Normal	—	—	—
5	1	Normal	— (0.5)	—	—	2.5	—	—	—	Normal	—	—	—

* Switching charging current at Northwest Station.
† Glow lamp voltages shown in parentheses; a dash indicates no record obtained on surge recorder film.

Table V—Tests on 66 Kv Line 6314, Crawford Station to Fisk Street Station

Length of line is 27,990 feet. Line is series transformer bonded throughout, except for 1 one-end bonded length adjacent to Fisk Street Station and 4 Kirke-Searing cross-bonded sections at scattered locations. The test section is one of these latter sections and consists of 442, 461, and 490 foot lengths. Measurements of voltage were made at locations normally having cross-bonding

		Voltages (Kv) Indicated by Surge Voltage Recorders and Glow Lamps†											
		31st Street and Central Park Avenue (5,640 Ft From Crawford Station)								31st Street and St. Louis Avenue (6,100 Ft From Crawford Station)			
			Crawford Side		Across Insulators			Fisk Street Side			Crawford Side		
Test No.	No. of Switching Cycles*	Sheath Bonding Connections	A ϕ Grd.	B ϕ Grd.	A ϕ	B ϕ	C ϕ	B ϕ Grd.	C ϕ Grd.	Sheath Bonding Connections	B ϕ Grd.	C ϕ Grd.	Across Insulator of C ϕ
1	2	Open	2.5 (2)	2.6	6.3	4.9 (4)	3.3	2.6	2.5	Normal	—	—	—
2	1	Open	— (2)	2.5	5.6	7.2 (4)	6.3	3.0	2.6	Normal	—	—	2.5
3	2	Normal	— (1)	—	—	2.5 (2)	—	—	—	Normal	—	—	—
4	2	Normal	— (0.5)	—	—	— (1)	—	—	—	Normal	—	—	—
5	1	Normal	— (0.5)	—	—	— (2)	—	—	—	Normal	—	—	—

* Switching charging current at Crawford end.
† Glow lamp voltages are shown in parentheses. A dash indicates no record obtained on surge recorder film.
Note: The cathode ray oscilloscope data for conductor surges shown on figure 4 were obtained during tests 1 and 2, and during additional tests in which no sheath voltages were measured.

nounced. The voltages to ground across the transformer coils were restricted to values of about 9 kv or less even though the open circuit voltages reached values of 14 kv to ground or 33 kv across insulators (at test location near switching point). About the same reduction in voltage was secured by replacing the transformers with either resistors or capacitors alone of the values indicated in table II (see figure 3 for connections). Still greater reduction was obtained by using combinations of transformer and resistors or capacitors in parallel.

In one set of tests not recorded in table II, switching was done at both ends of the line. The average voltages to ground and across the insulators were about 10 kv and 20 kv, respectively, in manholes near the switching end, when the connections of the bonding transformer were open. The corresponding voltages with transformers normally connected were roughly 3 kv and 6 kv. In these tests, the transient voltages in manholes near the end of the line remote from the switching end were always less than the minimum (2.5 kv) that can be indicated on recorders.

Oscilloscope data indicated that a large majority of the sheath potentials were oscillatory, only 2 or 10 per cent being unidirectional. About 40 per cent of the recorder films indicated unidirectional surges; but this fact does not indicate that the remainder were definitely oscillatory, since for each film there were a few cycles of switching, and unidirectional surges of opposite polarity might have been recorded on the same film. At the same time, some of the indicated unidirectional surges may have been very highly damped oscillations, only the initial peak being indicated on the films.

The frequency of the oscillations observed on the sheaths of the 10 mile line 6341 varied from 2,000 to 23,000 cycles per second. The lengths of the wave fronts were from 20 to 200 microseconds, while the entire disturbances lasted from 100 to 750 microseconds. The highest voltage observed by oscilloscope from sheath to ground was 3 kv.

Line 6313. A series of tests was made on the 5 mile line 6313 which has Kirke-Searing cross-bonding *throughout* (see table III). Measurements were made on the terminal length at Crawford and about 1 mile away. The voltages at the latter location when switching at Crawford were about the same as those obtained at 32d Street and Hamlin Avenue for line 6341, which was about $^3/_4$ mile from Crawford.

When switching was done at the Fisk Street end of the line, the data confirmed the results obtained on line 6341, that is, the sheath voltages were higher near the switching end of the line and negligible voltages appeared at the far end. Likewise, when switching was done at Crawford, the sheath voltages for the cable length adjacent to the circuit breaker were 3 to 4 times as high as for the test location 1 mile from the Crawford end. The voltages for the terminal length at Crawford were, roughly, 10 kv to ground and 20 to 25 kv across the insulating sleeves.

Line 6342. Tests were made on 10 mile line 6342. (see table IV). The bonding is of the star type throughout, except for 5 sections of cross-bonding. The measurements were made at the middle one of

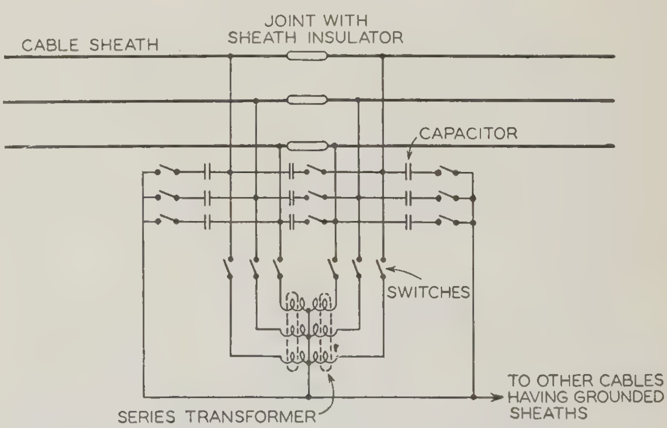
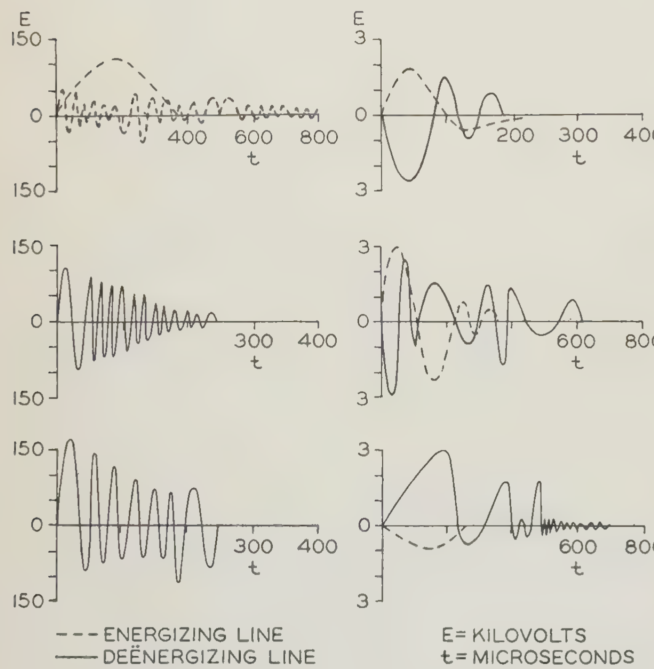


Fig. 3. Method of making connections to cable sheaths having H & M series transformer bonding

A typical test set-up is shown. In other tests, resistors were connected in place of, or in parallel with, the capacitors. Surge voltage recorders or other measuring devices were connected between various points in the circuit. Tests were made with switches open or closed

3 adjacent cross-bonded sections, about $^{3}/_{4}$ mile from the switching end. The sheath voltages with the cross-bonding connections in place were about $^{1}/_{3}$ as high as those for line 6313. The transient sheath voltages with the cross-bonding connections in place averaged about $^{1}/_{4}$ as high as with open bonding connections.

Line 6314. This line is 5 miles long and has series bonding, except for 5 scattered sections of cross-bonding. The sheath measurements were made on one of the cross-bonded sections about 1 mile from the switching end (see table V). The data show that the voltages to ground when the cross-bonding connections were in place, were about $^{1}/_{2}$ as high as when the bonding connections were open.



Conductor-to-earth transients at switching end of 5 mile line 6314

Sheath-to-ground transients on series-bonded 10-mile line 6341 (see table II)

Fig. 4. Typical voltage transients on interrupting charging current of 66-kv underground cables

In some of these tests, and in supplementary tests, the conductor surges were observed by cathode ray oscilloscope connected to the secondary of the *C*-phase potential transformer at the switching end of the line, and oscillograms were drawn by observers (see figure 4). These show characteristics very similar to those observed on the oscilloscope for the sheaths of line 6341. The frequency of the conductor oscillations for the 5 mile line varied from 23,000 to 83,000 cycles per second as compared with frequencies of from 2,000 to 23,000 cycles for the sheath surges on the 10 mile line 6341. The maximum crest voltage was 165 kv from conductor to ground, or about 3 times normal. The oscillations produced by opening the circuit breaker tended to have higher frequencies and higher maximum values than those produced by closing the switch.

A few years ago tests were made of conductor voltage oscillations on a 5-mile 66-kv line similar to line 6314 with practically identical test connections and switching procedure. A magnetic type of oscillograph was used and oscillograms were obtained strikingly similar in general appearance to those reported by Berkey.[3] Damped oscillations of about 2,800 cycles occurred each time the arc restruck; this is about the natural resonance frequency of the line and power transformer. The magnetic type of oscillograph was too slow to record the higher frequency oscillations disclosed by the cathode ray oscilloscope in tests on line 6314. Probably both sets of frequencies, or a wide range, were present.

The data indicate that the sheath surges on line 6314 were of essentially the same nature as those on the other lines tested. Since the initiating surges on the conductor were predominantly oscillatory, it seems reasonable to conclude that the sheath surges on the specially bonded 66 kv lines in Chicago were caused mainly by the production of high-voltage high-frequency surges on the line conductors by switching charging current.

Sheaths and Sheath Insulators. Flashovers across the $1^{1}/_{4}$ inch outer surface of the Waukegan sheath insulators caused no perceptible damage. No flashovers or evidence of flashovers were observed during the tests or at other times on the Chicago insulators, which have external and internal leakage distances of $3^{3}/_{4}$ and $1^{1}/_{2}$ inches, respectively. Also, careful examination of lengths of single conductor cables removed from various lines has disclosed no perceptible damage to the sheaths from transient sheath potentials—a record confirmed by the power companies of New York, Philadelphia, and St. Louis, which have been using a great many sheath insulators. Similarly, no sheath damage has been found in Chicago from lightning potentials approximating 40 kv from sheath to ground.[2]

Theoretical Analysis and Discussion

Any disturbance initiated on a line having distributed electrical constants must be propagated initially along the line as a traveling wave. It can be shown (see appendix) that, regardless of the type of bonding, the transient sheath voltage for a traveling wave initiated on any one conductor will be highest at the first 1 or 2 bonding points. At these points the surge is divided into a multiplicity of surges on all conductors, sheaths, and "earth" (sheaths of other cables). In the ideal case for cross-bonding, or for series transformer bonding without solidly bonded points, the transmitted surges on the conductors can travel along the remainder of the line without either further reflection or further production of sheath voltages. In practice so many factors differ from those of the ideal case that residual sheath voltages will appear at every specially bonded point. The energy represented by these residual effects comes from the wave front of the conductor surge, and rapidly depletes the front as the wave travels along the line. Normal attenuation also is operative and the wave front becomes "stair stepped" and smoothed off to a long sloping front, which soon becomes a major fraction of the line length. Then the disturbance rapidly develops into a set of stand-

ing waves which are maintained by the sputtering arc and continue to oscillate at a variety of resonant frequencies natural to the line and connected apparatus.

This sequence of events becomes considerably more complicated when surges originate on all 3 phases. The cross-bonding or series transformer bonding connections couple the sheaths together and introduce a strong mutual effect between phases, although it would be much less for a line with open end or solid bonding throughout. Separate and nearly simultaneous arcs are drawn on the 3 line conductors. Different phase conductors and associated terminal apparatus probably have at least slightly different natural frequencies. The principal result of these circumstances is to introduce beat frequencies in the oscillations, an effect observed by Berkey.[3]

The action may be compared with the behavior of 3 similar violin strings linked together at unequal intervals by springs, and set in vibration separately and almost simultaneously. A wave first will travel down each string and then quickly develop into a complicated set of "standing waves" having natural and beat frequencies; in time the waves will die out because of the dissipation of energy. In the light of this analogy, the reasons for the following field observations become clearer:

1. In accordance with theoretical expectations, higher frequencies were observed on a short line than on a long line (see figure 4). The Waukegan bus leads were so short that the frequencies must have been about 1,000,000 or 2,000,000 cycles per second.

2. Switching load resulted in the smallest sheath voltages and energizing a line generally resulted in smaller voltages than deënergizing. When switching load at least one end of the line always is connected to terminal apparatus, which decreases the natural frequency and the sheath voltages and also introduces factors promoting rapid attenuation. When deënergizing a line the arc is more prolonged and both ends of the line are freed of terminal apparatus, resulting in higher frequencies and less dissipation of energy. It must be recognized, however, that these considerations may not hold when switching large loads, particularly if the power factor is low, since the switching arc may be more severe.

3. Sheath voltages measured by surge recorders in the first section adjacent to the switch and within a few hundred feet of the switch were larger than at locations a mile or so away and were negligible at the remote end of the line. Despite this the transformer failures in service and during tests were not confined to the first few sheath lengths adjacent to the switch, but were distributed somewhat uniformly along the 10-mile line; most of the switching was done at the Crawford end. Examination of the failures indicated pitting, melting, and bridging of copper across the puncture path, indicative of sustained large currents and not typical of surges.

Apparently the greater energy of the oscillating surges was responsible for the final breakdown of the windings. An internal flashover alone would have no effect on the serviceability of the transformer. The initial puncture might have been attributed to either traveling waves or oscillations. The former would be more probable near the switching end; the latter, however, might reach breakdown values almost anywhere except at the far end of the line. The locations of voltage maximums in the standing waves would depend on the frequencies of the oscillations, which varied widely.

4. Sheath voltages appearing at any given point on a line are determined by the kind of bonding on other portions of the line as well as at the point in question, just as in the analogy the amplitude of vibration of one string at any selected point is a function of the interlinkages along its entire length in addition to the interlinkage at the point in question. In particular, attention should be called to the fact that voltages measured at 1 or 2 points in the line with bonds removed as in these tests are not at all representative of the voltages to be expected on a line open-bonded throughout. So far as could be determined experimentally or theoretically, the behavior of the conductor and sheath circuits was consistent with theories advanced by Brinton, Buller, and Rudge[4] and discussion with reference to sheath potentials by Beck.[4]

5. Check calculations based upon the theory give numerical results of the right order of magnitude, which is all that can be expected. Definite checks with particular cases are not feasible, since each item of test data is a composite of 2 or more switching operations, making it impossible to distinguish between voltages resulting from oscillations and voltages resulting from traveling waves. It is reasonable to assume, however, that the sheath voltages at 32d Street and Hamlin Avenue on line 6341 (see table II) resulted mainly from oscillations, as indicated by the oscilloscope data. The frequencies averaged about 7,000 cycles per second. The crest voltage of the conductor oscillations may be assumed to have averaged about 60 kv, on the basis of the tests on line 6314 (see figure 4). The corresponding crest current from equation 4 (see appendix) would be about 2,000 amperes, since the surge impedance of the cable is about 30 ohms. The sheath voltage to ground for a 66 kv cable having one-end bonding is calculated (see appendix) to be 9 kv per 1,000 feet for 2,000 amperes and 7,000 cycles. In test 1, the sheath length was 1,000 feet and the measured voltages were 8.4 kv on *B* phase and 7.2 kv on *A* and *C* phases. The conditions were not strictly equivalent to one-end bonding, however, because of the presence of the transformer coil in the ground connection.

In the case of line 6313, where the sheath voltages adjacent to the switch were 300 to 400 per cent higher than at a location a mile farther away, it seems reasonable to assume that the surge recorder indications resulted mainly from the initial traveling wave. Although the crest voltage of the conductor surge might have been from 60 to 150 kv (1 to 3 times normal 60 cycle crest) only a small fraction of this would appear on the sheaths, even for the length adjacent to the switch, since the wave front of the surge would be quite slow. The measured sheath voltages to ground confirm this view, the values being about 10 kv for the terminal length, and 3 kv for the location 1 mile away from the switch.

In the case of the Waukegan bus, the traveling wave theory suffices to account for the occurrence of voltages high enough to cause insulator flashovers. The heating of the resistors to incandescence, however, was probably caused by sustained oscillations, since the initial traveling wave could hardly have contained the requisite energy.

Methods of Protection

In the light of the theoretical analysis, the results of the tests in which resistors and capacitors were installed to limit the sheath voltage may be discussed more intelligently. In the case of the Waukegan bus, the calculated mutual reactance between conductor and sheath is about 25 ohms. This in series with the impedance of the protective device shunted across the sheath insulator would be the major impedance of the sheath current circuit on which the impressed voltage was about 100 kv. The 1 ohm resistor probably had considerably higher resistance at the very high frequency under consideration, because of skin effect. If its effective resistance increased to about $3^1/_2$ ohms, which seems reasonable, then the calculated surge potential across the shunt resistor would check with the measured value of 12 kv (i. e., $100 \times 3.5/28.5 = 12$ kv). The 14 microfarad capacitor, however, would have an impedance of only 1/180 ohm at 2,000,000 cycles per second. When shunted across the insulator it would reduce the voltage to $100{,}000(1/180) \div 25$ or only 22 volts. The combination of resistor and capacitor in parallel would be slightly more effective. Tests showed that the potentials were less than 45 volts in these cases.

For conditions such as those at Waukegan, the insulators are protected most effectively by shunt capacitors of 10 microfarads or more. The method successfully adopted for reducing the transient sheath

potentials to safe values from the standpoints of personnel and equipment was to shunt each sheath insulator with a 15 microfarad capacitor in parallel with 2 1-ohm resistors.

The sheath circuits for the series and star connections used with bonding transformers in Chicago are much more complicated than the bus at Waukegan. To attempt to check theoretically the results obtained in the tests involving resistors and capaci-

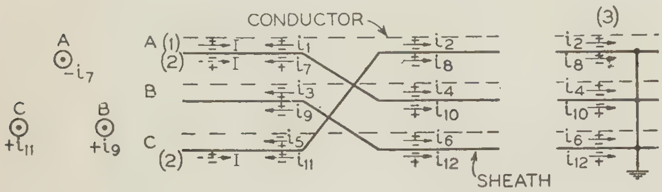


Fig. 5. Traveling wave at cross-bonded point

Numerals in parentheses refer to cases 1, 2, and 3 of text

tors on line 6341 would involve so many assumptions that the results would be worthless. However, it is easy to see in a general way why the shunt devices were much less effective than at Waukegan. In test 7, table II, a 33 ohm resistor was inserted between sheath and ground in the test manhole (bonding transformer disconnected) and the other end of the 1,000 foot sheath length was grounded through the bonding transformer coil. The average frequency of the induced sheath voltages was about 7,000 cycles and the calculated magnitude about 9 kv. Probably the resistor represented an appreciable fraction of the total sheath circuit impedance, since skin effect would increase its resistance and saturation would decrease the effective impedance of the transformer. The impedance of the unsaturated transformer coil would be about 120 ohms at 7,000 cycles (1 ohm at 60 cycles). Saturation would occur at about 1,800 volts. Thus a substantial part of the 9 kv impressed voltage would appear across the 33 ohm resistor. The 2 microfarad capacitor (test 9) would be more effective, having an impedance of only 11 ohms, but the voltage drop across it probably still would be a few kilovolts; tests indicated about 2.6 kv.

When the shunt devices are paralleled with the transformer, the combined impedance is appreciably less, thus reducing the voltage as indicated in table II. However, in order to reduce the voltages to satisfactory values, the impedance of the shunt protectors would have to be so small as to introduce undesirable characteristics, such as excessive heat losses at 60 cycles in the case of resistors or large physical dimensions in the case of capacitors. In addition, studies showed the installed cost of the shunts to be uneconomical.

The best solution of the problem of transformer protection appeared to be either some form of low voltage arrester or an increase in the strength of the layer insulation of the transformer windings. Suitable arresters or gaps could not be applied readily under Chicago conditions. The method of using ample insulation was adopted, since its feasibility and economy were demonstrated clearly by the satisfactory operating experience with the large majority of the bonding transformers which had sufficient insulation, and since the method did not require auxiliary equipment.

If external shunts are to be used for protecting the bonding transformers, they should be connected between phase and neutral rather than directly across the sheath insulator, since voltages may exist from sheath to ground even though none exists across the insulating sleeve.

Suggested Future Tests

Tests that might be made to supplement and check the results presented in this paper are as follows:

1. Determination of maximum sheath potentials adjacent to the switching end and some distance therefrom for short leads at terminals and for lines of various lengths that have various types of bonding.

Table VI—Traveling Wave at Cross-Bonded Point

	Current and Voltage Ratios, Fig. 5		
	Cross Bond		End of Section
Ratio	Case 1	Case 2	Case 3
i_1/I	$2z/D$	$4z/D$	
i_2/I	$(8x+z)/D$	$-4z/D$	$(64x^2+3z^2)/D^2$
i_3/I	z/D	$2z/D$	
i_4/I	z/D	$2z/D$	$(24xz+3z^2)/D^2$
i_5/I	z/D	$2z/D$	
i_6/I	z/D	$2z/D$	$(24xz+3z^2)/D^2$
i_7/I	$4x/D$	$-3z/D$	
i_8/I	$4x/D$	$8x/D$	$64x^2/D^2$
i_9/I	0	0	
i_{10}/I	$4x/D$	$8x/D$	$-32x^2/D^2$
i_{11}/I	$4x/D$	$-3z/D$	
i_{12}/I	0	0	$-32x^2/D^2$
e_{AB}/I	$-2xz/D$	$4xz/D$	Bond Wire to Ground
e_{BC}/I	0	0	
e_{CA}/I	$2xz/D$	$-4xz/D$	
e_{AA}/I	$4xz/D$	$8xz/D$	Across Insulators
e_{BB}/I	$2xz/D$	$4xz/D$	
e_{CC}/I	$2xz/D$	$4xz/D$	

Note: $D = (8x + 3z)$.

2. Determination of the character of conductor and sheath transients by means of cathode ray oscillograms.

3. Determination of the nature and magnitude of surges on the conductors and on the sheaths of lines to which the following have been applied on 1 conductor and on all 3 conductors of a dead line: (*a*) d-c. surge and (*b*) sustained oscillations of various frequencies from an oscillator. The sheath surges would be determined at several points along the line to see whether voltage or current nodes existed along the line. Also using the oscillator, resonant and beat frequencies as well as effective line impedance at such frequencies would be determinable for actual lines with all their complexities of sheath circuit conditions.

Appendix

Traveling Waves on Cross-Bonded Lines

Let figure 5 represent a point on a line where the sheaths are cross-bonded. The cables are assumed to be equilaterally spaced and remote from earth. The surge impedance between conductor and sheath is x and between sheaths is z. For case 1, indicated by the solid-line arrow, the surge current I is assumed to be applied between A-phase conductor and sheath only and for case 2, indicated by the

dotted arrow, between sheaths of A- and C-phase cables. In either case the surge is split up into reflected and transmitted currents and voltages. Arbitrary signs are assigned to each pair of image charges. For example, the signs on the arrow for i_7 indicate negative charge on the sheath of A-phase cable, and the plus sign refers to that part of i_9 and i_{11} on the other sheaths corresponding to i_7.

The solutions for the currents i (see table VI) in cases 1 and 2 are obtained by use of Kirchoff's laws. These solutions show that the impact of the surge I cannot change the potential of the bond BC. The latter is taken as a reference point, and is considered to be at zero potential to earth. The voltage equations (see table VI) readily are obtained from the relation that the voltage of a surge is equal to the product of the current and the surge impedance.

With the solutions of cases 1 and 2 in hand, the progress of a surge I entering on A-phase conductor and traveling across a complete section of cross-bonding may be examined. The fractions of the original surge that finally reach the far end of the section (case 3, figure 5) are given in the right-hand column of table VI. Only the conductor currents i_2, i_4, and i_6 are transmitted into the next section, since the sheath currents i_8, i_{10}, and i_{12} are totally reflected at the solidly bonded point.

Numerical values for the currents are obtained by substituting values of 31.5 and 112 ohms for x and z, respectively The latter figure is approximate, since no data are available for the surge impedance of circuits in a medium consisting mainly of damp concrete and air. Upon substitution, i_2, i_4, and i_6 are found to be 30, 35, and 35 per cent, respectively, of the original surge current I. Thus only about 30 per cent of the energy of the original surge is transmitted

Table VII—Traveling Wave at Series Bonded Point

Current and Voltage Ratios, Fig. 6

Ratio	Conductor Surge, Case (1)	Sheath Surge, Case (2)
i_1/I	$2ze'/3D$	$-ze'/D$
i_2/I	$1-2ze'/3D$	$-ze'/D$
i_3/I	$ze'/3D$	$-ze'/2D$
i_4/I	$ze'/3D$	$-ze'/2D$
i_5/I	$4xe'/3D$	$-(2xe'/D) + (1 - e'')$
i_6/I	$4xe'/3D$	$-(2xe'/D) + e''$
i_7/I	$2xe'/3D$	$-(xe'/D) + (1 - e'')/2$
i_8/I	$2xe'/3D$	$-(xe'/D) + e''/2$
i_9/I	$1-2e'/3$	$-2 + (e' + e'')$
i_{10}/I	$1-2e'/3$	$(e' - e'')$
i_{11}/I	$e'/3$	$1 - (e' + e'')/2$
i_{12}/I	$e'/3$	$-(e' - e'')/2$
e_{AA}/I	$4xze'/3D$	$-2xze'/D$
e_{BB}/I	$-2xze'/3D$	$zxe'\ D$
e_9/I	$2xze'/3D$	$-(xze'/D) - ze''/2$
e_{10}/I	$-2xze'/3D$	$(xze'\ D) - ze''/2$
e_{11}/I	$-xze'/3D$	$(xze'/2D) + ze''/4$
e_{12}/I	$xze'/3D$	$-(xze'/2D) + ze''/4$

NOTE: $D = (2x + z)$; $e' = e^{-2xzt/3MD}$; $e'' = e^{-zt/3M}$.

into the second cross-bonded section, and is about equally divided between the 3 conductors.

The progress of the surge after it has become equally divided between the 3 conductors can be deduced from the equations by cyclical rotation of subscripts and additions. It is found that if dissipation is neglected the surge travels undiminished along the line, but the sheath potentials become zero everywhere. For cross-bonded lines under actual field conditions, therefore, it is concluded that:

1. A traveling wave (switching surge) starting between conductor and sheath of 1 phase of a 3-phase cross-bonded line would become about equally divided between the 3 cables in passing through the first cross-bonded section, equivalent to about 1,000 feet of line.

2. After passing the first cross-bonded section, only residual or differential voltages would appear on the sheaths, these being due to nonsymmetry of duct spacing, unequal cable lengths, unequal velocities of propagation inside and outside the sheath, etc.

3. Each cross-bonded section acts as a wave trap for the residual voltages and multiple reflections, and attenuation would cause a steep wave front to be "stair stepped" into a long sloping wave front in the first few thousand feet of line.

TRAVELING WAVES ON SERIES BONDED LINES

Analysis of the behavior of surges at locations having series transformer bonding (see figure 6) is complicated by the effects caused by the 3-phase iron-cored bonding transformer. Terms of the form $M\ di/dt$ are introduced to take account of the voltage drops across the transformer coils. The symbol M represents the flux linkage per coil, leakage flux being neglected. The internal and external surge impedances of the cable are represented as before by x and z. Solutions obtained by operational analysis are given in table VII for the following: case 1—rectangular surge applied between conductor and sheath of A-phase cable; case 2—rectangular surge applied between A-phase cable sheath and the sheaths of B- and C-phase cables in parallel.

The exponential terms in the current and voltage equations all reduce to 1 at time $t = 0$ and to zero when $t = \infty$ so that investigation of particular cases becomes an easy matter. For equal surges on all 3 cables applied between conductor and sheath, it is found that no reflections occur at the transformers and the sheath voltages remain zero everywhere. For such a set of surges, therefore, the series transformer bonding is equivalent to cross-bonding. For surges not applied symmetrically, the transformer would become saturated rather rapidly and introduce substantial changes in the transients given by the equations in table VII, the principal result being a more rapid completion of the remainder of the transient.

Another interesting case is that of a surge between conductor and sheath of 1 cable accompanied by a surge only $^2/_3$ as large between the sheath of same cable and the sheaths of the other 2 cables in parallel. The combination is equivalent to (case 1 plus $^2/_3$ case 2). The front of the wave passes through the transformers without hindrance and at the first instant the potentials across all sheath insulators are zero. The potentials from sheath to ground, however, are not zero.

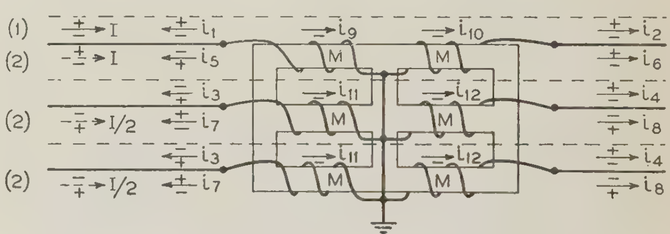


Fig. 6. Traveling wave at series bonded point

Numerals in parentheses refer to cases, 1, 2, and 3 of text

Hence, protective devices, if used, should be connected from sheath to ground. After the first instant a redistribution of potentials takes place.

These cases show the fallacy of the rather general impression that a concentrated inductance always completely reflects the front of a rectangular wave. In the bonding transformer the inductance is almost purely mutual, the self-inductance or leakage flux being

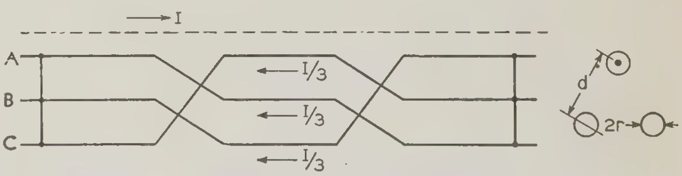


Fig. 7. Oscillation on cross-bonded line

negligible. Instead of the currents in the transformer coils being zero at the first instant, it is the energy stored in the magnetic circuit that must be zero. This is accomplished by the instantaneous occurrence of finite currents in the coils, having values governed by the external circuit except for the limitation that the magnetomotive force around each closed loop of the transformer core must be zero. The surge voltages across the coils likewise take up finite initial values depending on the initial distribution of currents in the external circuits. As the transient progresses, the voltages change in proportion to the rates of change of the currents in the coils. The expo-

nentials in table VII show that the initial conditions tend to persist longer for larger values of mutual inductance M.

The neglecting of the self-inductance of the transformers has been justified by considering the time constants of the transient effects that the self-inductance would produce. From test data on values of self- and mutual inductance it is found that transients due to the former would last only from $^1/_2$ to 2 microseconds, as compared with time constants of 40 to 2,000 microseconds for the transients in table

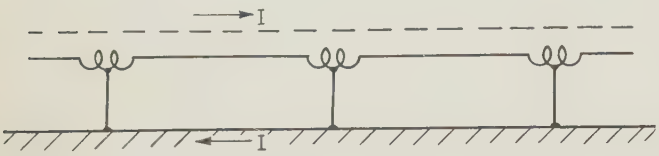


Fig. 8. Oscillation on series bonded line

VII due to mutual inductance. The only practical effect on surges of the closed secondary of the transformer is to reduce the self-inductance.

The solutions in table VII for currents and voltages readily are adapted for waves of any desired characteristics, as well as for those of simple rectangular form. Thus the progress of a surge passing through several transformers in succession may be investigated. It is found that regardless of the number of transformers encountered, no new exponentials enter the equations, so that the currents and voltages always may be expressed in terms of e' and e''.

OSCILLATIONS

An oscillating current on 1 conductor of a cross-bonded line is assumed to return about equally divided on the 3 sheaths (see figure 7). The induced sheath voltages are:

$$E_A = (^2/_3)2j\omega I \cdot \log_e(d/r) \tag{1}$$

$$E_B = E_C = -(^1/_3)2j\omega I \cdot \log_e(d/r) \tag{2}$$

The frequency reactance ω per 1,000 feet at 1,000 cycles is 0.192 and for 66 kv cables in Chicago the logarithmic term reduces to 1.71. Numerical values for the sheath voltages per 1,000 feet per 1,000 amperes at 1,000 cycles per second (see figure 7) are, therefore:

To Ground (Volts)			Across Insulators (Volts)					
			AA		BB		CC	
A	B	C	Left	Right	Left	Right	Left	Right
437	219	219	656	656	656	0	0	656

For any other cable length, frequency, or conductor current, the voltages may be found by direct proportion.

For series bonding (see figure 8) it is assumed that all return current for one conductor flows in earth or neutral. The calculated voltages per 1,000 feet per 1,000 amperes at 1,000 cycles per second become $E = 656$ volts, $E_A = 328$ volts, and $E_{AA} = 656$ volts, respectively, per sheath length, sheath to ground, and across sheath insulators.

The fundamental oscillation frequency for a cable short-circuited at one end is $f = 1/4\sqrt{LC}$. For cables having a permittivity (S.I.C.) of about 3.3, this reduces to

$$f = 25{,}000/L \tag{3}$$

where L is the length of the line in miles.

The maximum voltage and corresponding maximum current for each harmonic frequency of a standing wave or oscillation are related by the same expression as for traveling waves, that is:

$$E = IZ \tag{4}$$

where Z is the surge impedance. In the case of oscillations, however, the conductor current and voltage maximums are spaced alternately along the cable, whereas they are coincident for traveling waves.

From the foregoing data, the sheath potentials induced by oscillations may be calculated numerically for any underground line if the voltage of the oscillation is known or assumed.

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Application of Electron Tubes in Industry

Several of the circuits and principles of application of the various types of electron tubes in industrial control are considered in this paper. Principal consideration is given to the various types of photo-electric control, electron tube-reactor theater lighting control, electron tube motor control, and electron tube welder control. Principles intended as guides in the selection of the proper tube circuits are given.

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THE art of electron tube application is now several years old. During this period there have been evolved certain circuits and principles of application which, because of their peculiar fitness for the field, have almost come to be recognized as "standards." It is the purpose of this paper to discuss several of these circuits and to indicate typical applications in which they have found use. The observer will be impressed by the fact that electron tube control has made a place for itself in the industrial field by enabling things to be accomplished which are difficult or impossible to accomplish otherwise, and that as yet electron tube control has for economic reasons been unable to displace estab-

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lished apparatus except in a few instances. It is to be expected that electron tube control will encroach more upon the field of established apparatus when production volume has allowed unit costs to be reduced so as to meet competition with present methods.

Simple Photo-Electric Relay

The electronic device which has found the widest use up to the present time is the simple photo-electric relay. A device of this type utilizes the change in photo-electric effect caused by a substantial change in the light flux impinging upon its photo-electric tube to operate, through the proper amplifying equipment, a relay capable of handling the power required for the control function.

Since no power is required of an object to intercept a beam of light, and since the light beam cannot be damaged or worn out, this type of photo-electric relay is used in a large number of applications as a limit switch to control various electrical functions or as a production counter, responding to the presence of some object too light, or too fragile, or too heavy, or too hot, or too highly polished, etc., to permit satisfactory operation with ordinary mechanical switches.

These relays are used in automatic weighing processes; in steel mills to control automatic sheet catcher tables, conveyors in heat treating furnaces, the operation of rod or merchant mill shears, "kick-off" on "run-out" tables; in machines for grading ball bearings; for the automatic inspection of battery caps for vent holes and in many other applications.

A photograph of a typical relay of this type, removed from its case, is shown in figure 1, and its circuit diagram is shown in figure 2. This relay

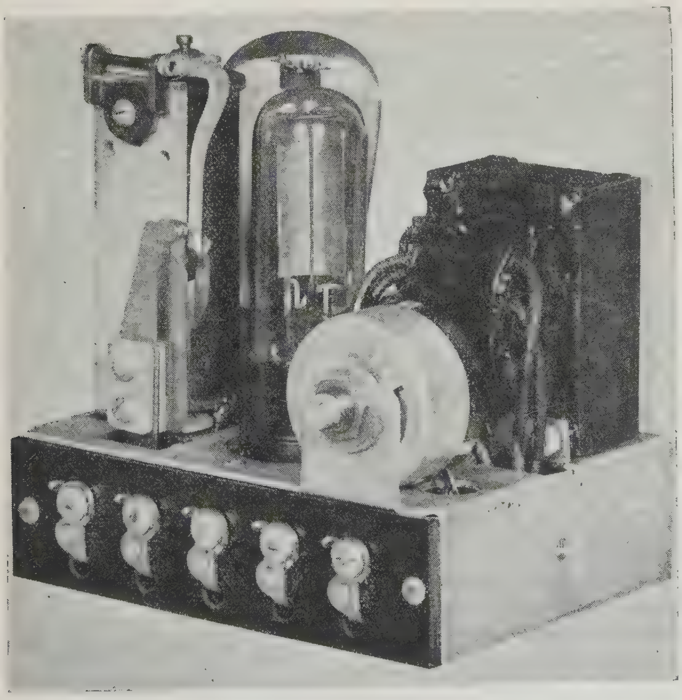


Fig. 1. Simple a-c photo-electric relay

operates as follows: When terminal A of the transformer secondary is positive, both the triode amplifier tube and photo-electric tube anodes are negative, hence no current flows in either circuit inasmuch as electron tubes are inherently rectifiers. (No attempt is made in this paper to explain tube characteristics. The reader will find convenient the paper

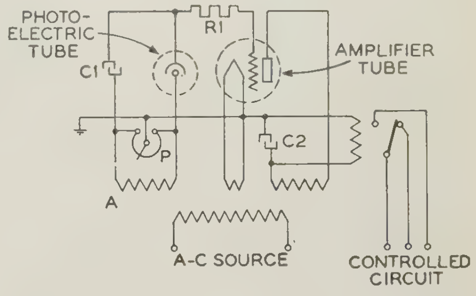


Fig. 2. Diagram of connections of the simple a-c photo-electric relay

"Electron Tubes in Industry" by W. R. King, A.I.E.E. Transactions, volume 50, 1931, pages 590–8.) However, if $C1$ be considered to have zero charge the grid of the amplifier tube will be positive when terminal A is positive and grid current, limited by grid resistor $R1$, will flow to charge grid capacitor $C1$ in the sense indicated on the diagram. Upon reversal of the a-c voltage, the amplifier tube and photo-electric tube anodes become positive, but the amplifier tube grid is negative by an amount equal to the charge of the capacitor plus the voltage from terminal A to the slider of potentiometer P, and, therefore, no current flows in the amplifier tube anode circuit. But if there be light on the photo-electric tube, current passes through it to the capacitor in the direction which tends to discharge the capacitor and charge it in the opposite sense. As the voltage across the capacitor decreases and finally reverses, the amplifier tube grid is made less and less negative with respect to the cathode and finally reaches a potential which permits current flow in the anode circuit. The current of the amplifier tube at first flows largely into the smoothing capacitor $C2$ inasmuch as the inductive effect of the magnetic circuit of the sensitive relay tends to maintain zero magnetic flux linkages in the relay coil at the beginning of current flow in the anode circuit. Shortly after anode current of the amplifier tube starts to flow the anode voltage of this tube again reverses and anode current stops. However, current flows in the local circuit composed of the capacitor $C2$ and the coil of the sensitive relay until the energy stored in that circuit is dissipated in the coil resistance. $C2$ is made sufficiently large that it is enabled to maintain continuous current through the coil of the relay between pulses of the amplifier tube anode current before the average value of the current in the relay coil reaches the value necessary to operate the relay. Hence, the relay has but small tendency to chatter at the critical average current value for pick-up. This complete series of events is repeated each cycle as long as there is light on the photo-electric tube.

With no light on the photo-electric tube, the action during the half-cycle when terminal A is positive is

the same as before. But in this case, when the a-c voltage reverses, practically no current flows in the photo-electric tube and therefore capacitor $C1$ is not discharged but maintains its negative charge and keeps the grid negative throughout the positive half-cycle, thereby prohibiting flow of current in the amplifier tube anode circuit.

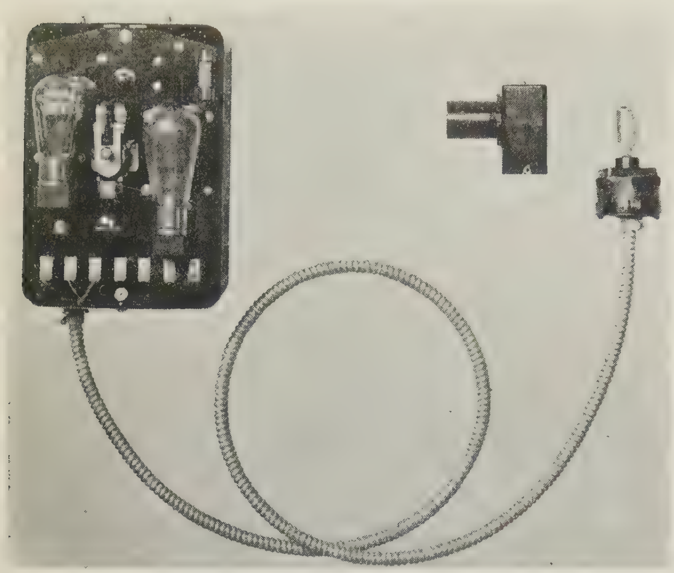


Fig. 3. Sensitive, high speed a-c photo-electric relay operating a grid controlled vapor discharge tube

Adjustment of the circuit is accomplished by means of potentiometer P, the position of which determines how far capacitor $C1$ must be discharged by the photo-electric tube current to permit current to flow in the anode circuit of the amplifier tube. The average value of anode current of the amplifier tube is therefore determined by 2 factors: (1) The value of light flux impinging upon the photo-electric tube (the magnitude of photo-electric tube current is a function of the magnitude of the light flux); and (2) the potentiometer adjustment.

A relay of the type shown in figure 1 operates with a minimum illumination of 5 foot candles on the photo-electric tube and upon a 50 per cent change in light which lasts for not less than 0.066 second (assuming a 60 cycle source of power) and will operate up to 400 times per minute. Its contact tips are rated one ampere, noninductive, at 115 volts.

Sensitive High Speed A-C Photo-Electric Relay

Some applications require greater sensitivity or a somewhat greater speed of response than it is possible to obtain with the above relay. In these cases a relay of the type shown in figure 3 may be applied, especially if the device to be operated be a small solenoid or other small magnetic device which may be operated directly from the grid controlled vapor discharge tube in place of the contactor shown, thus saving the time required to operate the magnetic relaying contactor. That is, the relay of figure 3 employs the photo-electric tube amplifier circuit of figure 2 to operate a grid controlled vapor discharge tube. Hence, since an arc discharge of a grid controlled vapor discharge tube will establish itself within a few microseconds after its grid receives the tripping impulse, power is applied to the relaying contactor or operating solenoid in minimum time (for an a-c circuit).

Relays of this type are used in tooth paste tube machines to align properly the end crimp with the printing on the tube, in steel mills to respond to radiant energy from hot bodies, and in slow speed package wrapping machines to insure correct register of the printed matter upon the wrapper to the package.

The circuit of this relay, shown in figure 4, operates as follows: As before, an increase in light on the photo-electric tube causes an increased average

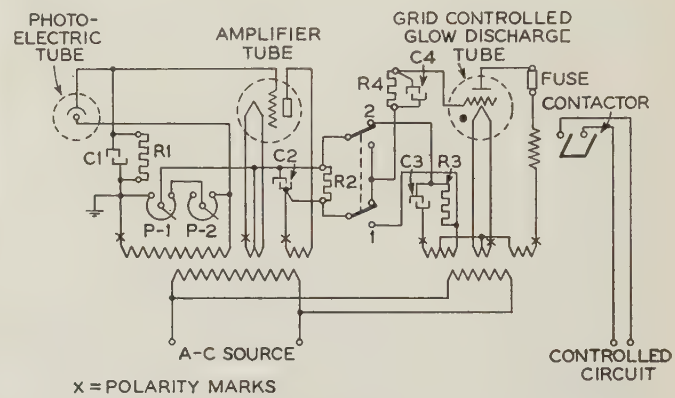


Fig. 4. Diagram of connections of the relay shown in figure 3

plate current flow through the amplifier tube, but due to the a-c circuit and to the time constant of the local circuit of $C2$ and $R2$ (over one-half cycle at 60 cycles) anode current flows through the amplifier tube in quarter-cycle pulses (while the anode voltage of the grid controlled vapor discharge tube is negative) to charge $C2$ and so produce a bias voltage in the grid circuit of this latter tube. Inasmuch as different applications demand that an adjustment be provided so that this tube in one case may be made to conduct upon light increase, and in another may be made to conduct upon light decrease, a change-over switch is provided between the photo-electric tube-amplifier circuit and the circuit of the grid controlled vapor discharge tube to allow the polarity of the tripping voltage introduced into the circuit of the latter tube by the amplifier to be reversed.

With the change-over switch in position 1 and zero current being passed by the amplifier tube, the voltage conditions in the circuit of the grid controlled vapor discharge tube are as shown in figure 5A; i. e., an a-c grid bias voltage 180 degrees out of phase with the anode voltage is used to charge $C4$ through the grid-cathode circuit of the grid controlled vapor discharge tube. The time constant of the local circuit of $C4$ and $R4$ is less than $^1/_8$ cycle at 60 cycles per second, yet is sufficient to carry the grid negative enough before the anode becomes positive so that

incidental shifts of anode voltage phase caused by current flow through the contactor coil are insufficient to cause the tube to fire erratically. With the relations of figure 5*A*, the anode current is zero.

If the amplifier tube is caused to pass more and more current, the conditions of figure 5*B* finally obtain; i. e., due to the a-c bias voltage superimposed on the difference in voltages existing on *C*4 and *C*2, the grid of the grid controlled vapor discharge tube is more positive than the critical grid voltage at the beginning of the half-cycle during which the anode of this tube is positive. Hence, full current is passed by the tube.

However, if the change-over switch be thrown to position 2 and there be zero anode current in the amplifier tube, the conditions of figure 5*C* obtain; i. e., an a-c voltage is introduced into the grid circuit of the grid controlled vapor discharge tube from the mid-tap of the bias winding and the junction of *C*3

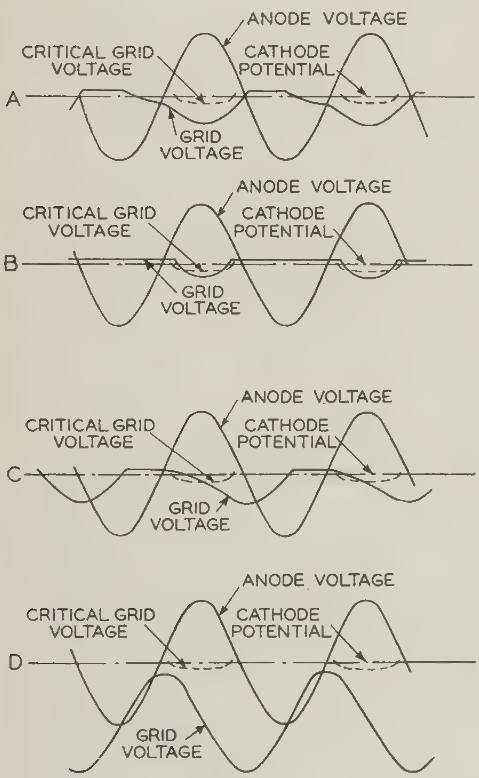


Fig. 5. Voltage relations of grid controlled vapor discharge tube of the relay shown in figure 3

and *R*3 which leads the anode voltage of this latter tube by slightly less than 90 degrees. This voltage charges *C*4 in a quarter-cycle pulse and holds the grid positive at the beginning of the half-cycle during which the anode is positive. Hence, full current is passed by the grid controlled vapor discharge tube.

If, under the latter conditions the amplifier tube is caused to pass more and more current, the conditions of figure 3*D* finally obtain; i. e., the increasing voltage across *C*2 shifts the axis of the 90 degree leading a-c grid voltage in the negative direction until the critical grid voltage is no longer exceeded, and the grid controlled vapor discharge tube ceases to conduct.

Particular notice should be taken of the care used in the above circuit to provide grid voltages for the vapor discharge tube of the correct phase and ample magnitude such that the tube cannot but pass full or zero anode current—a necessary condition to prevent erratic operation of the device controlled by the tube.

In contrast with the relay of figure 1, the relay of figure 3 will operate with a minimum illumination on the photo-electric tube of one foot candle and upon a 40 per cent change in illumination at this value, or upon a 10 per cent change in illumination at 10 foot candles, provided these changes last 0.05 second or longer (assuming a 60 cycle source of power). Hence the relay will operate up to 600 times per minute, assuming that the device operated by the grid controlled vapor discharge tube will follow at that speed.

Ultra-High Speed Photo-Electric Relays—D-C Operated

Both of the above photo-electric relays require the light impulse to last an appreciable length of time for proper operation, due to the direct utilization of a-c voltages on the tube elements. Many modern processes, however, require a photo-electric relay which will respond to a light impulse lasting but a few microseconds. For example, many wrappers for packaged articles first have printing applied in a rotary press, then are removed to a machine which cuts the wrapper in register with the printing and applies it to the package. Here it is necessary, for accurate

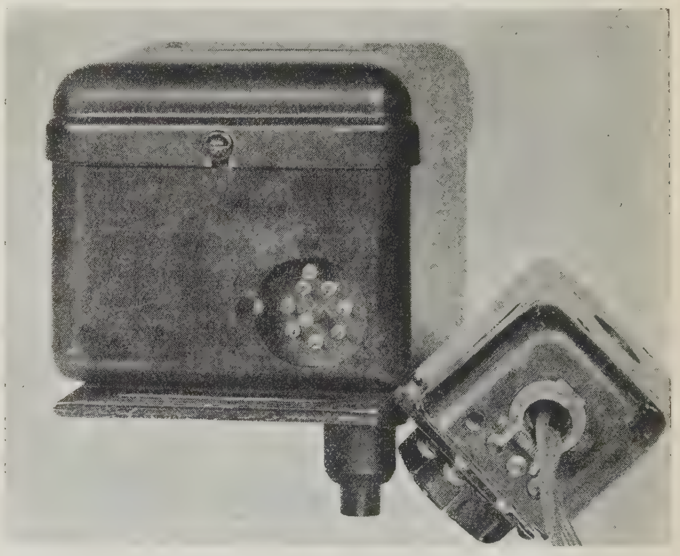


Fig. 6. Scanning head of the ultra-high speed photo-electric relay, d-c operated

high speed work, for photo-electric control apparatus to provide the synchronizing tie between the cutting knife and the printed matter on the web, because factors such as slip of the web in the machine and variations in stretch of the web preclude successful operation otherwise. And because it is essential that the photo-electric apparatus work on some small part of the printed design which may give but small photo-electric contrast with its background (or on some small mark printed specifically for the purpose)

and at the high web speeds possible in modern machines, an extremely sensitive and fast photo-electric device is required.

The type of relay shown in figures 6 and 7 has been found to be adapted to meet the exacting requirements of this type of service. Its virtues may best be understood, perhaps, from the following description of the operation of its circuit, shown in somewhat simplified form in figure 8. In order that the tubes may operate at any instant and be as free as possible from the transient voltage disturbances common on industrial power distribution lines, power is usually taken from the a-c power source used for incandescent lighting, modified in voltage by an electrostatically shielded transformer, rectified and carefully filtered by a full wave rectifier tube and pi filter. The practically pure d-c voltage thus derived is applied across voltage dividers from which are tapped the voltages required by the various tubes. Because of the high impedance of the photo-electric tube and the extreme speed at which this circuit must work, the photo-electric tube and amplifier are placed as close together as possible in a shielded enclosure known as the "scanning head." Usually the light source is mounted on the scanning head by a bracket, thus providing a unit which operates from change of reflected light which is relatively free of troubles due to moisture, dirt, electrostatic interference, or variations in focus. Sometimes, dependent upon the installation and upon the web material, the light source is mounted on the opposite side of the web from the photo-electric tube housing, thus providing a unit which operates upon transmitted light, which may allow a larger value of light flux to fall upon the photo-electric tube.

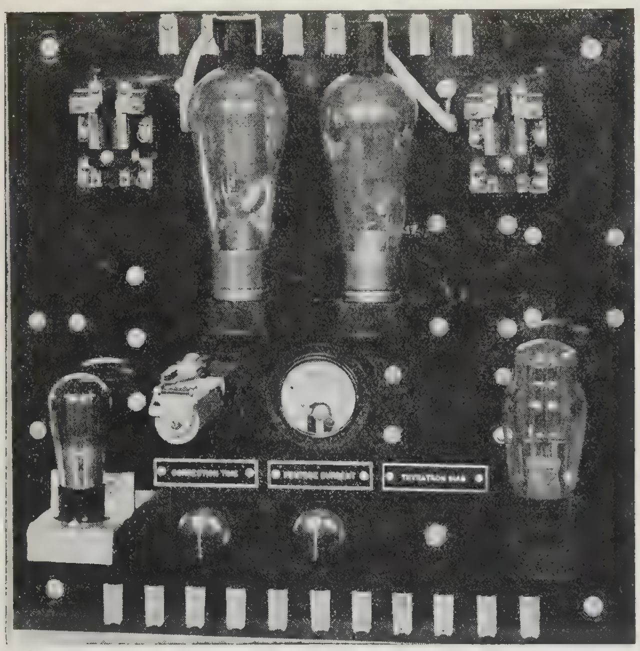


Fig. 7. Control panel of the ultra-high speed photo-electric relay, d-c operated

Due to the relatively high level of power output from the scanning head, however, the grid controlled vapor discharge tubes, control contactors, and rectifier may be mounted in a separate enclosure several feet from the scanning head in such a manner as to allow easy access, and in a position free from vibration.

Particular notice should be taken of the method of circuit coupling. Referring to figure 8, the photo-electric tube-amplifier circuit operates as follows When there is no change of light on the photo-electric tube, capacitor $C1$ assumes the potential existing across the photo-electric tube resistor, there is zero current flow in $R5$ and the amplifier tube grid is at ground potential, negative with respect to its cathode. However, upon change of light on the photo-electric tube, since the response of the tube is instantaneous, a new potential value exists across the photo-electric tube resistor. The voltage across $C1$ must finally equal the new voltage across the resistor but, since a capacitor cannot change its charge instantly, the difference between the old and the new voltage existing across the resistor must initially appear across $R5$, changing the grid potential of the amplifier tube by that amount. The grid potential will be carried in a more positive or a more negative direction, depending upon whether the capacitor is charged or discharged. Hence, due to the "capacity coupling" effect, the amplifier will respond to rapid changes of light but not to slow changes.

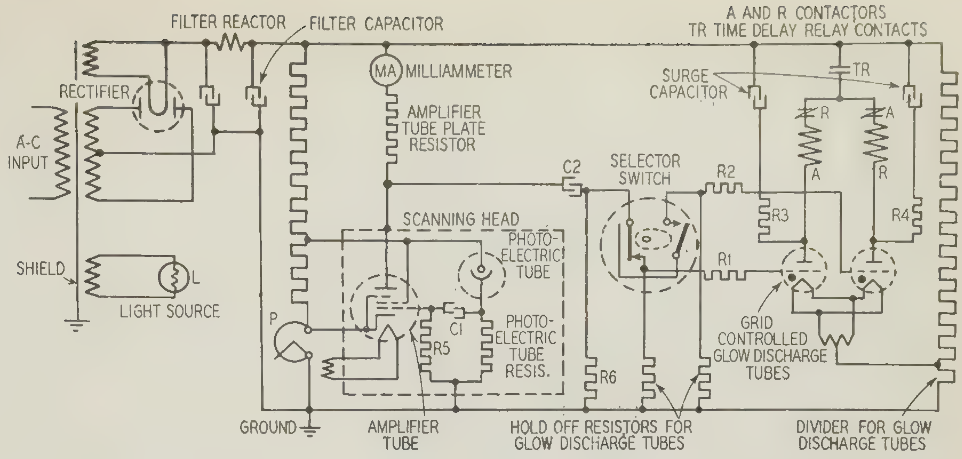
The pentode is used for the amplifier tube because its plate current is independent, roughly speaking, of the plate voltage value, if that value be kept above a certain minimum. Hence, high values of plate resistance may be used and great amplification secured.

The grid controlled vapor discharge tubes are normally biased negatively through hold-off resistors of moderately high value. Their grid circuits are carried through a selector switch and capacity coupled through $R6$ and $C2$ to the amplifier. Hence, if TR be closed, A and R be deënergized, one grid controlled vapor discharge tube or the other, according to the position of the selector switch,* will be in condition to be rendered conducting by its grid being carried positive by a voltage of correct polarity appearing across $R6$ (a circuit of low impedance). The tube, once fired, will remain conducting until TR is opened, even though the potential across $R6$ may have become zero meanwhile, or the selector switch contact opened, carrying the grid negative. A and R are the operating coils of contactors which operate to produce the required correction; while TR opens, then recloses after the desired correction period has passed, rendering the tube nonconducting again and putting it in condition to operate on the next proper impulse.

Relays of the type of figure 6 will operate on a minimum light change of 0.02 lumen occurring at an average rate of between 2 and 200 lumens per second.

* In applications such as the print-on-paper register control, 2 indications of position are required; one from the print itself, one from the cutting knife. The photo-electric tube obtains the indication from the print, while the selector switch which is geared in proper fashion to the cutting knife is the means of indicating in the tube circuits the position of the knife, and is also the means of choosing which of the grid controlled vapor discharge tubes should conduct.

Fig. 8. Ultra-sensitive high speed d-c register control using photoelectric tube and grid controlled vapor discharge tubes



Electron Tube-Reactor Theater Light Control

In the field of theater light control, electron tube-reactor dimming has come to be recognized as most efficient and most flexible. The saturable reactor is a device consisting essentially of 3 windings wound upon a multilegged iron core. Two of the windings are used to produce impedance in the a-c circuit, but are so placed upon the iron core and so connected that zero voltage is induced by them into the third, the d-c winding. The d-c winding is so wound upon the iron core that flux due to it tends to saturate the whole iron structure, causing the impedance offered by the a-c coils to decrease as the d-c saturating current increases. The saturable reactor losses may be kept at a value of roughly 2 to 3 per cent of the connected lamp load value at any lamp voltage in the dimming range (which represents a great advantage over resistance type dimmers). The tube units, reactors, and magazine circuit distribution panels may be located at the most economical distribution point and remotely controlled from a very small unit located in the position to give the operator maximum visibility; and due to the very small size of the control device at the operator's position several of these per lighting circuit may be provided by which complete lighting scenes may be set up in advance and brought into use as desired by the operator from a single control.

The lighting control circuit shown in figure 9 is of particular interest due to the so-called "feed-back" feature. For convenience and clarity the diagram has been divided into several parts.

A-C Power Circuit. The lamp load current passes through the line contactor, through a line fuse, through the several individual magazine circuit fuses, through the lamps, through the a-c winding of the saturable reactor *SR*, then to the neutral line. Since the a-c impedance of the reactor varies as a function of the d-c current flowing in its d-c winding, it is necessary to control the value of this d-c current in order to control the value of the voltage across the lamp load.

D-C Power Circuit. The direct current for saturating the reactor is obtained through the medium of a grid controlled vapor discharge tube *T* and a 2 electrode gas filled tube *P*. Power from the line is taken in pulses through the d-c winding of *SR* and *T*, the latter governing the average value of power taken. The energy caught in *SR* due to its inductance forces current through *P* and *R* during the half-cycle when *T* cannot pass current, being a rectifier. Thus, full wave rectified current flows in the d-c winding.

Grid Circuit of T—Turn On. The network located remotely in the master control board can be represented, as in figure 9, by a resistance type potentiometer *MCB* which produces a voltage whose magnitude may be varied but whose phase is of no consequence since the 2 electrode vacuum tube *K* rectifies this voltage and charges capacitor *FI*. The voltage across *FI*, for any given input from *MCB*, is practically constant because of the long time constant of the local circuit of capacitor *FI* and resistor *A* in comparison to the supply system frequency. If, at the instant under discussion, capacitor *FB* be assigned a zero charge, the voltage existing across *FI* carries the grid of *T* positive and *T* tends to pass maximum current.

Turn Off. However, the increase of current through the d-c winding of the reactor increases its saturation and causes its impedance to decrease, thus causing the lamp voltage to rise and the control transformer *CT* connected across the lamp, to charge capacitor *FB*. But the polarity of the voltage across capacitor *FB* is opposite to that across capacitor *FI*, and if the voltage of capacitor *FB* rises too high the net voltage applied to the grid of *T* is negative and *T* will cease to pass current, which would cause the lamp voltage to drop. However, the time constant of *FB* and its discharge resistor *A* is made more

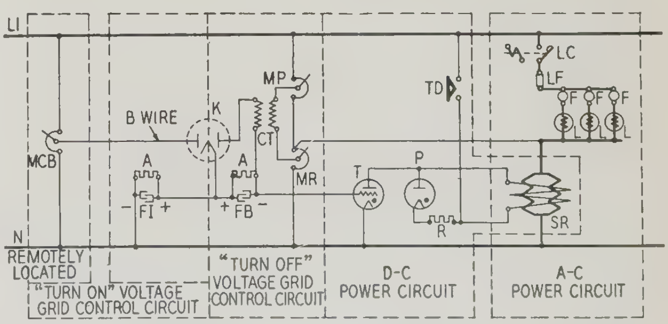


Fig. 9. Theater type electron tube-reactor control for light intensity

nearly comparable to a half-cycle of the system frequency, thus producing, in effect, an a-c voltage superimposed upon the difference of the 2 d-c voltages. The phase of this a-c voltage is such that as its axis is shifted by change in value of the d-c difference voltage, the phase angle at which it intersects the critical grid voltage of T is shifted, thus producing phase control of T. Hence, as the lamp voltage nears the correct value, T regulates and finally passes the correct value of current to hold the lamp voltage at the desired value.

Adjustments. Two adjustments are provided to compensate for conditions of the customer's installation and for variations due to manufacture of the parts. *MR* is provided so that T may be rendered completely nonconducting when *MCB* is in the zero intensity position, and *MP* is provided to adjust the lamp voltage to the correct value with *MCB* in the maximum intensity position. These adjustments are made quickly at the time of installation and thereafter are fixed.

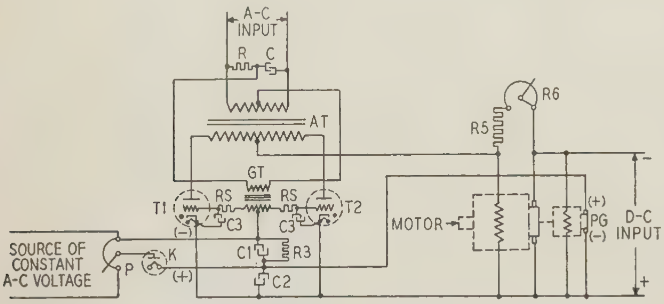


Fig. 10. Electron tube motor control

Particular heed should be paid to the comparison or "feed-back" feature of the circuit of figure 9 in which the result is compared to the cause. The general use of this principle in those applications in which the tubes are used to regulate power flow to devices provides accuracy, flexibility, and consistency. In the particular case of figure 9 in which the comparison feature is used to compare the lamp voltage directly to the voltage from *MCB*, the control operates to hold constant lamp voltage for a given setting of *MCB*. Hence: (*a*) The lamp load may be changed through wide ranges without affecting the lamp circuit voltage—a great advantage in stage pocket circuits into which bunch lights of various sizes are plugged; (*b*) the variations of characteristics of tubes or saturable reactors have small effect upon lamp voltage; (*c*) the a-c circuit is fast in operation compared to other reactor type dimmers, inasmuch as T passes full or zero current except when the lamp voltage is near the correct value, thus producing a forcing action; and (*d*) a voltage of any or variable phase may be received on the B wire since the circuit responds to the magnitude, only, of a voltage from that source. Thus, the potentiometer *MCB* may be entirely operated from a single phase while the loads are distributed over the 3 phases. Also, solenoids, involving no moving contacts, may be employed as potentiometers.

Due to the fact that but minute power quantities are required in the grid circuits of grid controlled vapor discharge tubes to affect control of these tubes, all apparatus, including "unit controls," "master controls" and the "fader" (if used) mounted upon the master control board at the operator's position, remain miniature in size. Also, since the tube unit responds only to a change in voltage magnitude received between the B wire and the neutral, any device may be used in the master control board network which produces a change in voltage. Hence, when scene "presetting" and scene to scene "fading" are required, small voltage regulators, one for each scene to be preset, are used as "unit controls."

By proper manipulation, through the "fader," of the voltages applied to the voltage regulator primaries, the control of the single tube unit may be transferred from one voltage regulator to any other as desired at any rate determined by the operator. That is, as the "fader" control is operated, the lighting circuit "fades" proportionately from its previous intensity to the intensity required in the selected preset scene. Obviously, there are no mechanical interconnections between any controls; the "mastering" and "fading" are accomplished through the same simple electrical network.

Electron Tube Motor Control

Control for d-c motors obtained by the application of grid controlled vapor discharge tubes has found use

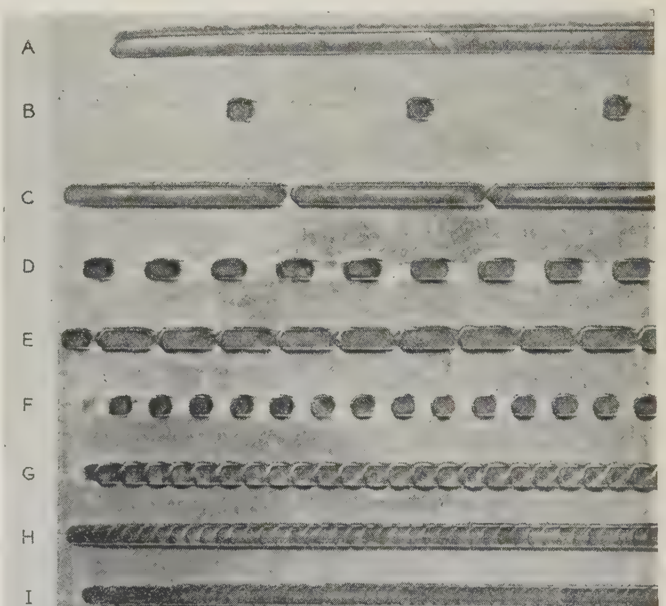


Fig. 11. Resistance welds made at approximately 7 feet per minute by line welder controlled by a control panel using grid controlled vapor discharge tubes

A. 21 spots per inch
B. Long off period, short on period
C. Short off period, long on period
D. Intermediate speed and ratio
E. Intermediate speed and ratio
F. $1^2/_3$ spots per inch
G. 3 spots per inch
H. $4^1/_2$ spots per inch
I. 6 spots per inch
J. 14 spots per inch

in many applications where stepless, accurate control of motor speed is sought, or where peculiar or unusual conditions prevent the ready adoption of rheostatic control. It is used for maintaining the correct tension during the reeling of the wire output of wire drawing machines, for correlating the speeds of the various sections of rubber process conveyors to maintain a given loop of rubber sheet between conveyor sections, for varying over wide ranges the speed of d-c motors driving frequency changers which supply power to high speed textile motors, and for maintaining the speed of the motors within narrow limits at any given setting in spite of wide load changes, etc.

Field or armature control may be used depending upon the application. However, armature control by electron tubes, except for highly specialized cases, has not been developed for reversing or regenerative applications, and field control is therefore used unless an unusually wide speed range is required.

A typical diagram for speed control of d-c shunt motors through the use of grid controlled vapor discharge tubes to control field strength is shown in figure 10. This simple circuit is applicable in those cases in which the mechanical and electrical circuit constants of the motor and load provide a system which is not particularly susceptible to hunting. As the diagram indicates, it is the practice only to boost to the required maximum value, with power from the grid controlled vapor discharge tubes, that value of field current (obtained in the orthodox manner from the regular d-c supply) which limits the motor speed to its rated maximum value, since this connection prevents the motor overspeeding if the tubes should fail. Here also, as in the case of the theater light control circuit of figure 9, a feed-back circuit compares, in the grid circuit of the tubes, voltages from the controlling potentiometer and from the pilot generator directly driven by the motor whose speed is being controlled. Hence, under any load conditions in the rated range of the motor, and in spite of possible variations in characteristics of these tubes, in d-c line voltage (the pilot generator field runs well saturated) or in motor field resistance, the tube circuit regulates the motor speed to a value which produces a pilot generator voltage which compares closely in value to the voltage from the controlling potentiometer.

In particular, the circuit of figure 10 operates as follows: The controlling potential from potentiometer P is used to charge capacitor $C1$ through the 2 electrode vacuum tube K. Inasmuch as the time constant of the local circuit of capacitor $C1$ and resistor $R3$ is made large in comparison to the time value of one cycle at the supply system frequency, P introduces practically a pure d-c voltage into the grid circuit of the grid controlled vapor discharge tubes. There this voltage opposes in polarity the voltage introduced into the grid circuit by pilot generator PG across filtering capacitor $C2$. Since GT superimposes upon the difference of these d-c voltages an a-c voltage, obtained from the bridge consisting of the primary of the power transformer, resistor R and capacitor C, lagging by 90 electrical degrees the anode voltage applied to the grid controlled vapor discharge tubes, effective phase control of these tubes may be obtained by varying the d-c difference voltage through small positive and negative values. Hence, the circuit regulates to produce a pilot generator voltage to compare closely in value in the grid circuit to the grid circuit voltage from potentiometer P, irrespective of load or circuit characteristic changes. Circuits of this nature may normally be expected to improve the regulation of a shunt motor to less than 2 per cent at any load or speed setting in the rated range of the motor.

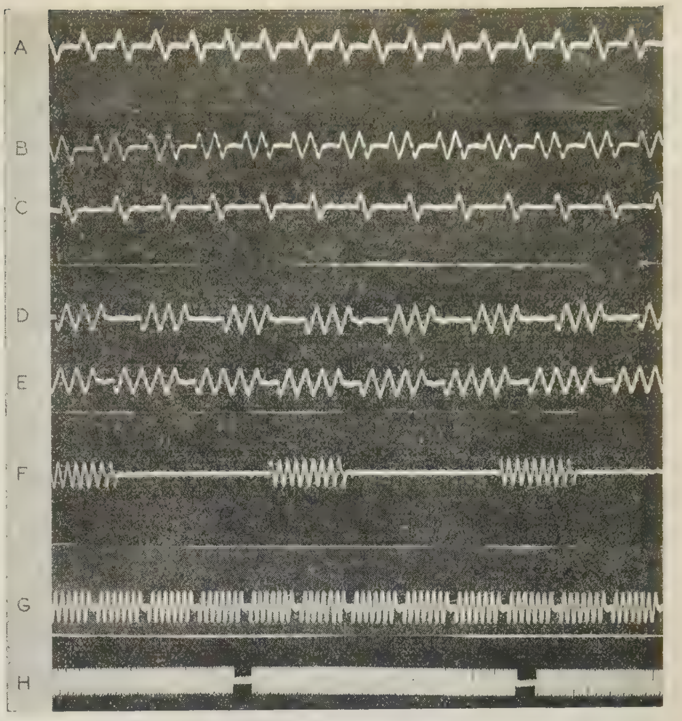


Fig. 12. Oscillograms illustrating range of control with electron tube control for resistance welding machines

A. 1 cycle on, 1 cycle off
B. 2 cycles on, 1 cycle off
C. 1 cycle on, 2 cycles off
D. 3 cycles on, 2 cycles off
E. 4 cycles on, 1 cycle off
F. 9 cycles on, 19 cycles off
G. 7 cycles on, 1 cycle off
H. 97 cycles on, 7 cycles off

Electron Tube Welder Control

A good example of the flexibility of electron tube control is that provided by using grid controlled vapor discharge tubes for the control of power flow to resistance welders. The development of this useful control has revolutionized the methods of fabrication of many high production units such as refrigerators, cans, small metal spools, etc., and has made it possible to weld metals consistently which were previously considered too difficult to weld for commercial practice. This control, used with line welders, produces, at high speed, gas and oil tight seams of excellent strength. Used with spot welders it produces consistently good welds as fast as the operator can handle the work. Figures 11 and 12 illustrate the flexibility and consistency of the control shown in figure 13, operated as a line welder.

In describing the operation of this control whose complete circuit is shown in figure 14, it is convenient

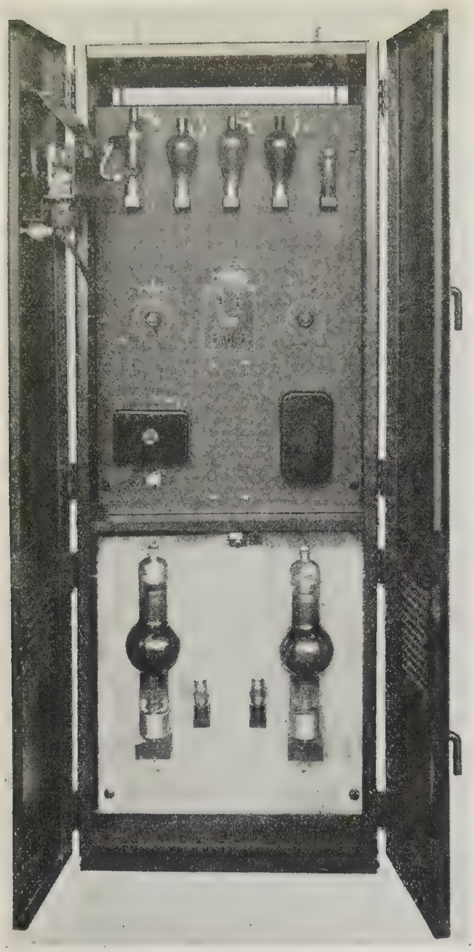


Fig. 13. Control panel for electron tube spot-welder and line-welder

to divide the circuit into several parts and describe the operation of each separately, from which the operation of the whole will become apparent.

Power Circuit. Because hot-cathode electron tubes are inherently low current, high voltage devices, a series transformer is interposed between the power tubes and one of the lines used to supply the welder; which line is, in effect, to be opened and closed to control the power flow to the welder. The use of the series transformer allows a small (exciting) current to flow when the power tubes are held nonconducting and introduces a small (leakage) reactance in the circuit when the power tubes are caused to short circuit the series transformer secondary, but these effects are generally negligible. To insure that the power tubes, $T1$ and $T2$, may be rendered completely nonconducting, a d-c bias is provided for each of the power tubes through the medium of full wave rectifier tubes $T7$ and $T8$ and filters composed of the local circuits of $C3$ and $R3$. Resistors $R7$ are provided to limit the grid current when the grid is carried positive with respect to the cathode. To protect the tubes from losing control due to voltage surges caused by the bouncing of contacts during the closing of circuits on either the primary or secondary side of the welder, a material having a negative resistance-current characteristic is placed across the series transformer secondary, and the grid cathode capacity of the power tubes is increased by the addition of capacitors $C2$. Hence, with the primary of the grid transformer TG open circuited the power tubes are held nonconducting, but upon the closing of power to TG a-c voltages of large value in phase with the anode voltages of $T1$ and $T2$ are superimposed upon the d-c biases and the tubes are rendered conducting, and power is applied to the welder.

It is clear that at the beginning of the "power on" period of a welding cycle that the grid controlled vapor discharge tubes must be rendered conducting at that instant during the a-c supply voltage cycle which produces minimum current transient in the supply lines. Otherwise, excessive peaks of line current due to saturation of the transformer iron and inconsistent welding results may be obtained. In the case of line welders, it is also clear that even numbers of half-cycles of the a-c line power must consistently be applied to the welder to insure that d-c line current components are not built up to saturate the transformer cores and cause high line current peaks to be drawn. Hence, the control circuit section of the circuit of figure 14 has been designed with the above limitations in mind.

Control Circuit. Actually, the control circuit controls the power supplied to the grid transformer TG of the power tubes in the same manner that the power

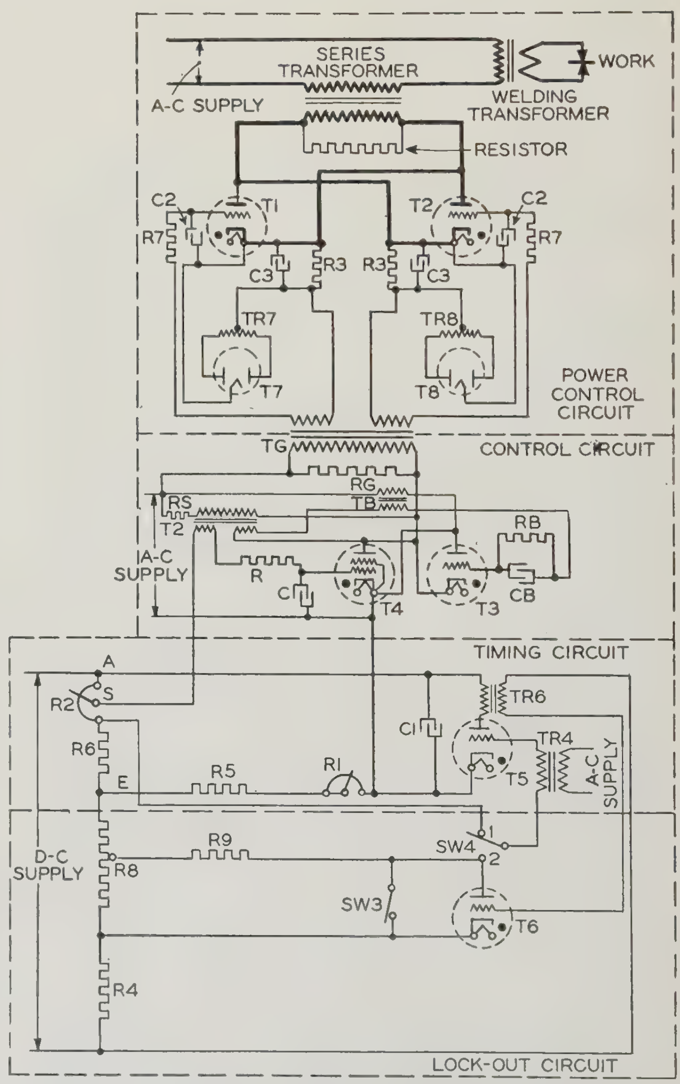


Fig. 14. Electron tube control for resistance welding

tubes control the power flow to the welder, except that the power required by *TG* is of such value that small grid controlled vapor discharge tubes, *T*3 and *T*4, may be placed directly in one lead of the a-c supply to *TG*, obviating a series transformer. The grid of tube *T*3 is normally biased negatively with respect to its cathode by the charge upon *CB* produced by grid cathode current flow due to voltage from *TB* during the time the anode of tube *T*3 is negative. Tube *T*4 is also normally held nonconducting by a negative bias from the timing circuit. However, should *T*4 be caused to pass a quarter of a cycle of current or more, transformer *T*2 will be energized simultaneously with the power tube grid transformer *TG*, and *T*2 will introduce into the grid circuits of both tubes *T*3 and *T*4 voltages which lead their anode voltages and are of sufficient magnitude to render *T*3 and *T*4 conducting. Hence, tubes *T*3 and *T*4 will continue to pass current until a negative bias again is introduced into the grid circuit of tube *T*4 of greater magnitude than the peak of the voltage from transformer *T*2. When this occurs tubes *T*3 and *T*4 will each finish out the remainder of the half cycle allotted to them and again become nonconducting, but ready to begin a new welding cycle. Tube *T*3 is a simple 3-element grid-controlled vapor-discharge tube, for ample power is available to control it, but tube *T*4 is a 4 element tube (a shield grid vapor discharge tube) containing argon instead of mercury vapor. This type of tube is used because it may be positively controlled with a minute amount of power, thus allowing the value of the current limiting resistor *R* to be high to reduce the load upon the timing circuit, and because its characteristics change but little over wide temperature ranges. As in the case of the power circuit, resistor *RG* and capacitor *C* are used to minimize voltage surges and their effect. It is obvious that the control circuit could be dispensed with if power tubes *T*1 and *T*2 could be positively controlled with the power values supplied to the grids of tubes *T*3 and *T*4.

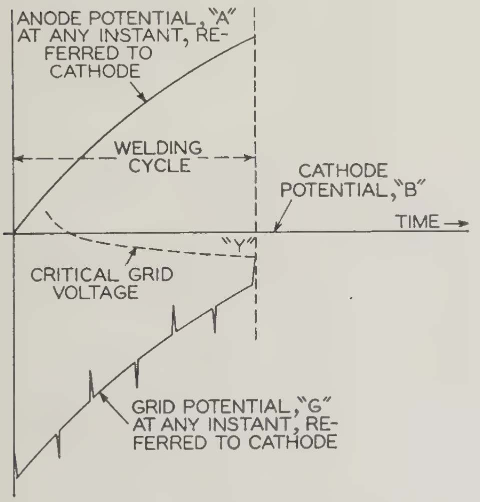
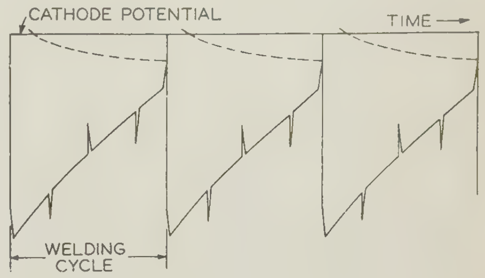


Fig. 15. Voltage relations of grid controlled vapor discharge timing tube, T-5, of figure 14

Timing Circuit. For the moment, let switch *SW*4 be thrown to position 1, disconnecting the lockout circuit, and let the operation of the timing circuit under line welding conditions be considered. Its action may be most easily understood, perhaps, by considering that *C*1 has zero charge at the first instant. Under this condition, the d-c voltage *A-E* appears across *R*1 and *R*5, the anode voltage of the grid controlled vapor discharge tube *T*5 is zero and its grid is negative by the value of the voltage *A-E* less the drop across *R*6. However, capacitor *C*1 immediately starts to charge at a rate dependent upon the setting of *R*1. But the voltage across *C*1 is applied to the anode-cathode circuit of tube *T*5 and also directly reduces the value of the negative grid-cathode bias. Hence, when the value of the voltage across *C*1 has increased to a certain critical value, the sharply peaked a-c voltage superimposed upon the reduced d-c bias, through the medium of the saturating transformer *TR*4, renders tube *T*5 conducting, whereupon capacitor *C*1 discharges through it and the commutating reactor-feedback transformer *TR*6. (The transformer feature is used with the lockout circuit and will be discussed later.) The reactor *TR*6 is used to limit the peak value of discharge current to a value within the peak current rating of tube *T*5 and to trap enough magnetic energy to over-discharge capacitor *C*1 and carry the anode-cathode voltage of tube *T*5 negative for a sufficient period of time to deionize this tube so that the grid bias, now grown again to a large negative value, may prevent the tube from passing current as capacitor *C*1 starts to charge in the normal sense. At the instant the capacitor charge becomes zero, this inverter, used for the timing circuit, has completed one pulse, and the sequence of events already described begins again. Figure 15 graphically illustrates the rise of anode voltage, the decrease of the d-c component of the grid voltage with the peaked voltage a-c component superimposed upon it, and the point *Y* at which the grid potential exceeds the "critical grid voltage" in the positive direction and renders the tube conducting. Figure 16 illustrates the variation of grid voltage and critical grid voltage over several cycles of operation. It is to be observed that the pulsing of the inverter is controlled by the peaked a-c voltage and is thus exactly synchronized with an even number of half-cycles of the a-c power supply. Hence, since one pulse of the inverter is defined as one welding cycle, and the instant of starting of the welding cycle with respect to the phase of the a-c supply voltage may be varied by varying the phase of the peaked a-c component of grid circuit voltage with respect to the line voltage, it is seen that only an even number of half-cycles of line voltage frequency may con-

Fig. 16. Variation of grid voltage and critical grid voltage of T-5 over several cycles of operation



stitute a welding cycle; and that power may be switched to the welder only at that instant during a line voltage cycle determined by the phase position of the peaked a-c voltage wave in the grid circuit of tube *T*5, since the varying d-c bias to control tube *T*4 in the control circuit is obtained from the timing circuit and applied to the control circuit in such manner that the grid of the "leading" tube (*T*4) of the control circuit is almost instantly carried from a large negative to a large positive value by the discharge of capacitor *C*1 through the timing tube (*T*5) to render conducting the "leading" control tube, *T*4. Thus, d-c current components in the line circuit are avoided, and minimum line current transients due to "switching" are obtained.

The length of a welding cycle is determined by the length of time required to charge capacitor *C*1 of the timing circuit to the critical value; while the ratio of time during which power is allowed to flow to the welder to the time during which power is prevented from flowing during the welding cycle is determined (assuming that the critical grid-cathode potential of tube *T*4 is zero volts) by the ratio of time that the grid of tube *T*4 is positive during the welding cycle to the time that it is negative. Inasmuch as the setting of the variable resistor *R*1 determines the rate of charge of capacitor *C*1, and the setting of the tapping arm *S* of potentiometer *R*2 determines the length of time that the grid of tube *T*4 may be positive during a welding cycle, it is seen that 2 very simple control devices provide complete flexibility as to required welding adjustments. Notice also that no moving parts are required except for setting up for new welding conditions.

Lockout Circuit. It is obvious that the above circuit combinations can be used for spot welding if an additional circuit be added to allow but one pulse to be made by the timing circuit. Such a circuit is connected to the timing circuit if switch *SW*4 be thrown to position 2. The normal set of conditions under which the circuit is ready to apply and time the power flow to the welder is: welder's control switch *SW*3 closed, placing grid of timing tube *T*5 at a large negative potential; timing tube *T*5 nonconducting; capacitor *C*1 fully charged, thus holding the leading control tube *T*4 nonconducting; anode voltage of lockout tube *T*6 zero, being short-circuited by *SW*3; and grid of *T*6 considerably negative. To initiate a power pulse to the welder, the welder's control switch *SW*3 is opened, thus reducing to a small negative value the d-c bias applied to the grid of the timing tube *T*5. Simultaneously d-c voltage from the voltage divider appears across the anode-cathode circuit of lockout tube *T*6 but, due to its negative bias, this tube remains nonconducting for the moment. At the next positive pulse of peaked a-c voltage, superimposed through transformer *TR*4 upon the now small negative d-c bias in the grid circuit of the timing tube *T*5, the timing tube will be rendered conducting, starting the welding timing cycle and power flow to the welder. The discharge of capacitor *C*1 through commutating reactor-feedback transformer *TR*6, however, induces a voltage into the grid circuit of lockout tube *T*6 which overcomes in the positive voltage direction the negative d-c bias always existing there and renders *T*6 conducting. With *T*6 conducting, the large negative d-c bias is reëstablished in the grid circuit of the timing tube *T*5, which prevents anode current in *T*5 from restarting after having been stopped by the anode voltage of *T*5 being carried negative by the electrical inertia of *TR*6. The lockout tube *T*6 being a grid controlled vapor discharge tube and having a d-c voltage applied to its anode, will continue to carry current to keep *T*5 nonconducting until switch *SW*3 is again closed, in spite of the fact that the grid of *T*6 was but momentarily carried positive by the pulse from *TR*6. Observe that practically no time is wasted in "resetting" the circuit for the next welding cycle, and that high speed spot welding introduces no problems.

Many of these controls, operating with line welders, are in constant (24 hour) use making gas tight seams in stainless steel at the rate of 72,000 welds per hour. The power controlled in this instance amounts roughly to 50 kva.

Principles Useful in Choosing Tube Circuits

Due to their unique properties, electron tubes have already proved themselves to be very useful tools in many industrial applications. However, as might be expected, these tubes have certain characteristics which become faults when used with apparatus for the industrial field. Nevertheless, experience has shown that most of these faults may be largely eliminated, in so far as their practical effect upon a desired result is concerned, by a careful choice of the circuit in which the tubes are used. As guides in helping to choose such circuits, the following few principles have been found useful: (a) If possible, but one tube should be used as the controlling element; (b) a "feed-back" circuit in which the result is compared to the cause should, in general, be used whenever the tube circuit is to regulate power flow to some device; (c) wherever possible, steps should be taken to insure that grid circuit voltages change at a high rate over wide ranges at the instant that control of the tube is required (thus, saturating transformers providing peaked voltages or capacity coupled circuits or some other expedient, according to the need, should be provided); and (d) inasmuch as tubes may respond almost instantly, the most careful layout of parts to obtain minimum intercircuit coupling, together with careful shielding and filtering is essential to avoid difficulty due to stray transient voltages.

Electron tube control has expanded in a healthy manner in the few years since the beginning of serious effort to apply it in the industrial field, in spite of the fact that it has had to contend both with the difficulties attendant to the introduction of apparatus of radically new concept and the fact that industry in general has been reduced to straits in which it has tended only to buy parts for the necessary upkeep of existing apparatus. It is believed that the return of industry to normal will cause a rapid expansion in the use of electron tube control, and that the above circuit principles will be found in general use.

Use of Vacuum Tubes in Measurements

For the benefit of those who may wish to use vacuum tubes in meeting specific problems in the field of measurement, the comprehensive bibliography contained in this paper has been prepared. Some 600 references are included in this list, selected from a total of about 1,500 papers or books published since approximately 1920. The first portion of the bibliography contains publications dealing with the characteristics of vacuum tubes, and the second portion contains references to specific applications to measurement problems.

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A CURIOUS situation exists with respect to the application of the vacuum tube to measurement problems. On one hand it is found that of all the various types of vacuum tube circuits which have been devised a very considerable proportion have been intended solely for use in measurements. On the other hand an extensive measuring technique, for both electrical and nonelectrical quantities, rests almost entirely upon the vacuum tube. Many measurements, including the fundamental measurements of length, mass, and time, have been carried to greater precisions by means of the vacuum tube. In other cases the tube has been instrumental in extending the range of measurable magnitudes.

In spite of its importance as an element in measuring apparatus there are relatively few cases in which a tube has been designed expressly to meet the requirements of a given measurement problem. The history has generally been that a tube, designed originally for use as a telephone repeater or as a radio broadcast detector, has been found to possess characteristics which could be utilized to advantage in an ultra-micrometer or in a fractional millisecond chronograph. The usual procedure in designing measuring apparatus involving the vacuum tube is to examine the characteristics and constants of existing tubes and then to adjust the associated equipment in such a way as to utilize as effectively as possible the most suitable tube. It must be noted, however, that this technique may at times prove a serious handicap and that a tube of special design may in certain cases be the best, or even the only, solution to a given problem. As a matter of fact, one suspects that the usual practice of adjusting the circuit to the tube is largely a question of the environment of the experimenter, and would be considered absurdly awkward by tube design engineers. The present material, however, is not prepared for tube design engineers, but has been collected at the request of the communications and electrophysics committees of the A.I.E.E. for the benefit of those who may wish to use vacuum tubes in meeting their own specific measurement problems. The more common practice is therefore adhered to and the utilization of those characteristics possessed by tubes already in existence is considered.

So much has been written regarding the behavior and use of the vacuum tube that a description of the innumerable applications of the tube to measurement problems is quite outside the scope of a paper of limited length. Even if it were possible such a discussion would be largely a repetition of what has already been said many times. It appears, therefore, that the present purpose may best be served by devoting the space available to a classified bibliography of those papers which are most likely to contain information of value to one contemplating the use of vacuum tubes in some problem of his own.

In preparing this bibliography it has been recognized that the vacuum tube is a functional element having fairly complex performance characteristics. One or several of these characteristics may be pertinent to a given application. The first portion of the bibliography has, consequently, been devoted to a survey of those publications which deal with the various characteristics of vacuum tubes or which discuss the theoretical aspects of their behavior. The second portion contains references to specific applications where these characteristics are utilized in representative types of measurement.

The bibliography goes back to approximately 1920, the date of publication of "The Thermionic Vacuum Tube" by van der Bijl. This book includes both a thorough treatment of the performance characteristics of the 3 element tube and a detailed analysis of the various uses to which this tube had been put up to that time. There is also an excellent general survey of prior art to be found in R. W. King's paper, "Thermionic Vacuum Tubes and Their Applications," published in 1923 (see reference 329). Since the time of these publications multigrid vacuum tubes and tubes with indirectly heated cathodes have come into extensive use. There have also been developed a number of special purpose tubes of particular interest in measurement work. These include the low grid current, or electrometer tube, the variable-mu tube and others. The demands of ultra-short wave radio have stimulated the design of tubes the geometry of which permits their use at frequencies beyond the range of the more familiar types. The gas filled tube, with its remarkably fast trigger action, has also found numerous uses in measurement work. In addition

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to having now available an increased variety of performance characteristics from which to make a choice, a greatly improved knowledge of the fundamental relations associated with these characteristics is also available. The references in the present bibliography were selected from a total of about 1,500. The choice has been governed primarily by a desire to include papers which should constitute a collection covering broadly that information which forms the basis of the utilization of the vacuum tube in measuring apparatus. All titles have been translated into English.

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Constant-Current D-C Transmission

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High voltage d-c electric power transmission has been envisioned for many years, but numerous obstacles have prevented its use to any great extent. Most of these obstacles appear to be overcome in the system described in this paper; this system comprises conversion of constant-potential a-c power to constant-current d-c power, transmission of constant-current d-c power, and reconversion to constant-potential a-c power. The promising features of this system are its unusual stability and reliability; as an example, the high-voltage constant-current d-c line may be short-circuited without damage to line or equipment.

ADVANTAGES of direct current for high voltage power transmission have been recognized for many years, but general use of this method of power transmission has been prevented by numerous obstacles. In the Thury system, as developed in Europe, rotating machines are employed to convert the high-voltage d-c power into a-c power. The difficulties associated with this sytem are well recognized.

Development of the hot-cathode grid-controlled vapor-discharge electron tube has promised a satisfactory solution for the problem of transforming the d-c power into a-c power, but the performance of high-voltage constant-potential inverters never has been entirely free from difficulties.

A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted Oct. 4, 1934; released for publication Nov. 14, 1934.

The authors have conducted a series of developmental studies on a d-c transmission system employing a constant current inverter and rectifier. The transmission was over an artificial line at 10 amperes and 15,000 volts. The line was supplied from a 3-phase full-wave 10-ampere constant-current delta-wye rectifier, operating from a 150-kw 3-phase 550-volt motor-generator set. At the receiving end the power was fed into a 3-phase full-wave 10-ampere constant-current delta-delta inverter operating on the 550-volt 3-phase shop service of the General Electric Company at Schenectady, N. Y. The circuit is shown in the single line wiring diagram of figure 1.

The promising features of these developmental studies center largely around the equipment employed for converting constant-potential a-c power into constant-current a-c power, and conversely.

Monocyclic Network

Some 45 years ago, Paul Boucherot invented the use of a series resonant circuit, as shown in figure 2, for transforming constant voltage into constant current for arc light circuits. Later, this type of circuit was studied thoroughly by Steinmetz. In "Alternating Current Phenomena," published in 1905, Steinmetz analyzes the simple resonant circuit of figure 2 for converting constant potential into constant current, or conversely. In "Theory and Calculation of Electric Circuits," published in 1897, he analyzes a bridge arrangement of 2 inductive and 2 capacitive reactors, as shown in figure 3. This arrangement Steinmetz calls a monocyclic square.

The term "monocyclic," as used by Steinmetz,

("Theory and Calculation of Electrical Apparatus," first edition, second impression, 1917, page 214) is applied to a polyphase system of voltages (whether symmetrical or unsymmetrical) in which the flow of energy is essentially single phase. It is thus well known that this circuit operates as a phase balancer, when supplying a single-phase constant-current load, and draws balanced power from a quarter phase system.

This paper is not concerned primarily with the phase balancing property of this circuit. However, all arrangements for converting constant potential into constant current, or the converse, that employ inductance and capacitance will be referred to as monocyclic networks.

In "Theory and Calculation of Electric Circuits," Steinmetz describes several polyphase arrangements of monocyclic networks. One of these arrangements, which is particularly valuable because of the wide use of 3 phase power, is shown in figure 4. If lines A, B, and C are supplied with constant potential, lines A', B', and C' will supply constant current. However, the network is perfectly symmetrical and reversible.

In the following discussion, Z' will represent the load impedance of one phase to the neutral, I' the constant current through this impedance, and I_a the current in phase A on the constant potential side; Z_1' and Z_2' will represent impedance branches of the monocyclic network and E_a, E_b, and E_c, the phase voltages of the constant voltage supply. These quantities are shown diagrammatically in figure 5.

It is easy to show that the following general vector equations describe this circuit for all conditions of operation:

$$I' = \frac{E_aZ_2' + E_bZ_1'}{Z_1'Z_2' + Z'(Z_1' + Z_2')} \tag{1}$$

$$I_1' = \frac{(E_a - E_b)\,Z' + E_aZ_2'}{Z_1'Z_2' + Z'(Z_1' + Z_2')} \tag{2}$$

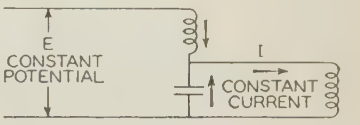
$$I_2' = \frac{(E_b - E_a)\,Z' + E_bZ_1'}{Z_1'Z_2' + Z'\,(Z_1' + Z_2')} \tag{3}$$

$$I_a = \frac{(3Z' + Z_1' + Z_2')\,E_a}{Z_1'Z_2' + Z'\,(Z_1' + Z_2')} \tag{4}$$

Balance

The quantities Z_1' and Z_2' are preferably pure imaginaries. At the resonant frequency these 2 quantities are equal. The operation of the monocyclic circuit is, however, in no way critical at the resonant frequency, and satisfactory operation may be obtained with considerable variation from the resonant frequency. Since the frequency of power systems is usually very nearly constant, the variation in relative magnitudes of Z_1' and Z_2' will be referred to as the balance of the monocyclic network.

Fig. 2. Resonant circuit for transforming constant voltage to constant current

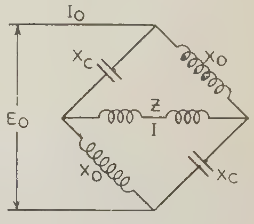


A circuit in which Z_1' equals Z_2' at the operating frequency will be referred to as a balanced monocyclic network. When the inductive reactance exceeds the capacitive reactance, the circuit will be described as inductively unbalanced, and conversely.

Phase Rotation

When a rectifier is operating from a monocyclic network, one phase rotation gives the best economy, whereas the reverse rotation is preferable for an inverter. The phase rotation shown in figure 5 is the preferred one for an inverter. The reason for this difference in phase rotation between the rectifier and inverter arises from the fact that in the circuit of figure 5 there is a constant voltage of half the phase voltage effectively in series with the constant current. When this series constant voltage is in such a direction as to increase the current, the condition is best for the rectifier. In an inverter it is best if this constant voltage is in such a direction as to absorb power.

Fig. 3. Circuit known as a monocyclic square



This condition may be demonstrated mathematically by a consideration of equations 2 and 3. In a rectifier the load impedance Z' has a positive real component, whereas in the inverter the load impedance has a negative real component. If the load impedance Z' has a positive real component, then Z_2' should be a negative and Z_1' a positive imaginary to give the smallest currents I_1' and I_2' and therefore the lowest inductive and capacitive kilovoltamperes for a given load.

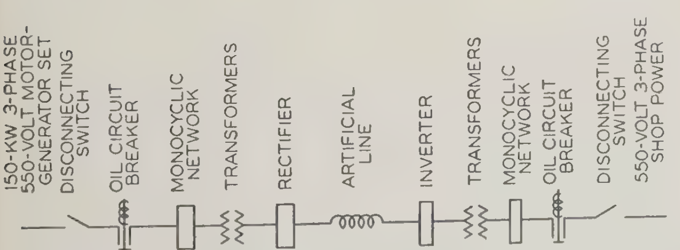


Fig. 1. Simplified circuit diagram of 150-kw 15,000-volt 10-ampere constant-current d-c transmission system

Power Factor

If a balanced monocyclic network be assumed, as shown in figure 4, equation 4, which gives the line current of phase A on the constant potential side, becomes:

$$I_a = \frac{3E_aZ}{Z_1'Z_2'} \tag{5}$$

Since Z_1' and Z_2' are pure imaginaries of opposite sign, their product is a positive real quantity, and the line current I_a leads the phase voltage E_a on the constant potential side by the angle of Z', the load impedance of the constant current side. On the constant current side,

$$E' = I'Z' \tag{6}$$

where E' is the load voltage, and the current lags the voltage by the angle of the load impedance. It is therefore evident that the monocyclic network reverses the power factor angle.

Steinmetz in his work states that the power factor is the same on the 2 sides of the monocyclic network. He fails, however, to point out that the power factor angle is reversed.

This reversal of power factor is of the greatest importance in the use of a monocyclic network in connection with inverters using grid-controlled vapor-

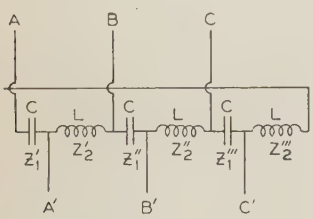
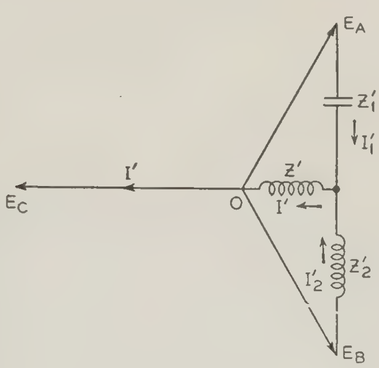


Fig. 4. A 3-phase monocyclic network

discharge tubes. It is well known that commercial loads ordinarily are lagging in phase, whereas an inverter using phase commutation will supply only loads that are leading in phase. By interposing a monocyclic network between the inverter and the load, it is possible to supply lagging loads and yet operate the inverter by means of phase commutation. This greatly simplifies the inverter circuit, and appears to avoid the necessity for using "harmonic

Fig. 5. Vector diagram for a 3-phase monocyclic network



commutation (see "Harmonic Commutation for Thyratron Inverters and Rectifiers" by C. H. Willis, *General Electric Review*, volume 35, 1932, page 632).

Utility

Assuming a balanced monocyclic network, as shown in figure 4, it readily may be shown that the ratio of output kilovoltamperes to monocyclic kilovoltamperes is highest, or the utility is greatest, when the absolute values of the load impedance and monocyclic impedances are in the relation:

$$Z' = \frac{Z_1'}{\sqrt{3}} = \frac{Z_2'}{\sqrt{3}} \tag{7}$$

This condition is independent of the power factor, but the value of the utility depends on the power factor. The load impedance as obtained by equa-

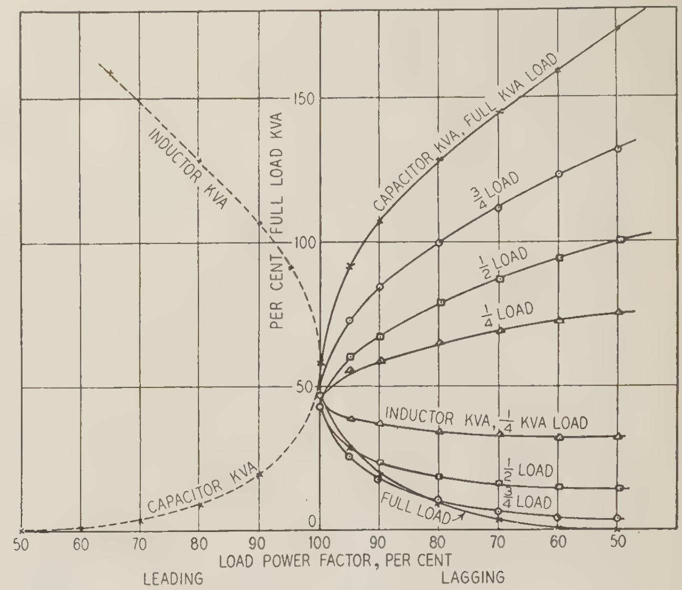


Fig 6. Capacitor and inductor kilovoltamperes in monocyclic network versus load power factor, with constant current inverter supplying power through the network to a constant potential load

tion 7 is the correct impedance for full load. Since the current is constant, half load will obtain with half this impedance, and no load will occur at short circuit. It is this response of the constant current circuit to the short-circuit condition that promises the greatest advantages over the constant potential system.

The curves of figure 6 give the capacitive and inductive kilovoltamperes for several values of load impedance with varying load power factors. These curves apply to a constant current inverter when operating through a monocyclic network to supply an inductive load at constant potential. It is evident from these curves that the capacitive kilovoltamperes required rises rapidly as the power factor of the load decreases. This rise in the capacitive kilovoltamperes by no means is fully compensated by the reduction of inductive kilovoltamperes because the capacitor must supply the kilovoltamperes necessary to reverse the power factor angle of the load in passing from the constant current to the constant potential side of the monocyclic network. For this reason it is desirable to operate the monocyclic network at the highest possible power factor. As the power factor increases, the time available for commutation and deionization of the inverter tubes is reduced. The 150 kw developmental apparatus has operated satisfactorily at about 95 per cent power

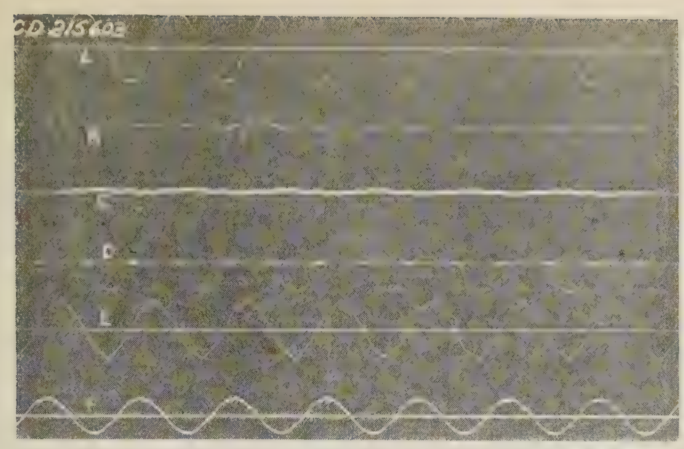


Fig. 7. Oscillogram for inverter operating on short circuit without commutating voltage

D-c line volts 0; d-c line amperes 9.8; capacitance volts 352; load 550 volts, shop

A. Line voltage, constant potential lines
B. Line current, constant potential lines
C. Line voltage, constant current lines
D. Line current, constant current lines
E. Monocyclic capacitance voltage
F. Monocyclic inductance voltage

factor. It would seem safe to assume that operation at power factors as high as 90 per cent readily may be attained. With lower power factors the time available for commutation and deionization is increased at the expense of greater capacitive kilovoltamperes.

Operating Characteristics

A constant potential inverter requires a grid phase shift of approximately 180 degrees to change from inverter to rectifier operation. A constant current inverter operating through a monocyclic network requires no grid phase shift to change from inverter to rectifier operation. The monocyclic network operates as a current regulator; when there is no impressed voltage, this network swings over and supplies a voltage to circulate the current, and the inverter tubes operate as rectifiers. If, now, a voltage be applied to the d-c circuit in such a direction as to tend to increase the current, the voltage of the monocyclic network reverses thus holding the current to the normal value. The apparatus thus automatically swings from rectifier to inverter operation, with the application of voltage. No change or adjustment of the grid phase is necessary in passing from inverter to rectifier operation. In this respect the constant current inverter operating through a monocyclic network is the only tube circuit known at this time that will regenerate or reverse power flow automatically.

In order to begin operation the d-c circuit is short-circuited and full potential is applied to the constant potential side of the inverter. Under these conditions the inverter begins operation as a rectifier and establishes full load current circulating through the short-circuited line. The voltage of the rectifier supply then is reduced somewhat below normal and the rectifier monocyclic network is excited. The rectifier then circulates a reduced current through the short circuit in the direction opposite to that of the current from the inverter. When rectifier and inverter are adjusted to give the same current, the short circuit, which carries the difference of the 2 currents, carries no current and the short-circuiting device may be opened. A further small rise in the current supplied by the rectifier causes the inverter to take load because the inverter monocyclic network tries to hold a constant current. In this way the voltage of the d-c line and the corresponding load may be established.

The load flow is controlled in a manner quite closely analogous to the control of load flow between 2 d-c constant-potential shunt generators operating in parallel. A small change in voltage of either shunt generator is sufficient to cause a large transfer of load. Similarly, in a constant current circuit, a small change in current is sufficient to cause a large change in voltage and, therefore, in load. A 5 per cent change in current is sufficient to effect a change in load from no load to full load.

A 2-electrode rectifier tube has been found to be a very satisfactory device for short-circuiting the d-c line when starting. This tube is connected in the proper direction to carry the current from the inverter. As the rectifier current is raised, the current through the short-circuiting tube decreases. When the rectifier current tries to exceed the inverter current, the tube ceases conduction and the system takes load. The short-circuiting tube then acts as an automatic reverse power relay and prevents the inverter from feeding back power if the rectifier voltage decreases. The circuit automatically is short-circuited if the inverter tends to reverse the power flow.

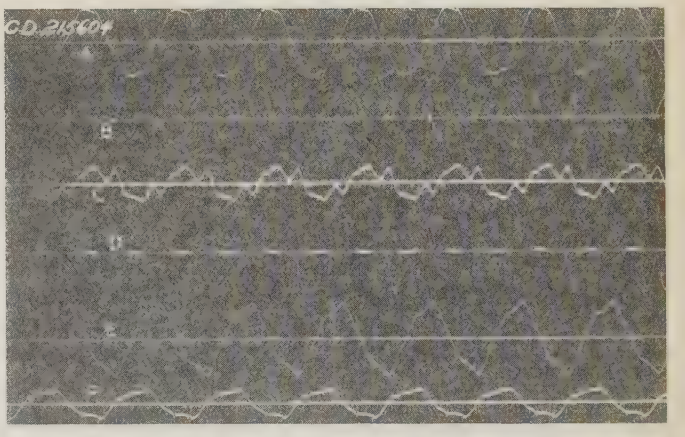


Fig. 8. Oscillogram for inverter operating on short circuit with full commutating voltage

D-c line volts 0; d-c line amperes 9.4; capacitance volts 448; load 550 volts, shop

A. Line voltage, constant potential lines
B. Line current, constant potential lines
C. Line voltage, constant current lines
D. Line current, constant current lines
E. Monocyclic capacitance voltage
F. Monocyclic inductance voltage

In case of an accidental short circuit on the line

connecting a constant current inverter and rectifier, the current through the short circuit is much less than the line current, because only the difference between the no load currents of the rectifier and inverter is available for the short circuit. The short-circuit current may be of the order of 10 per cent

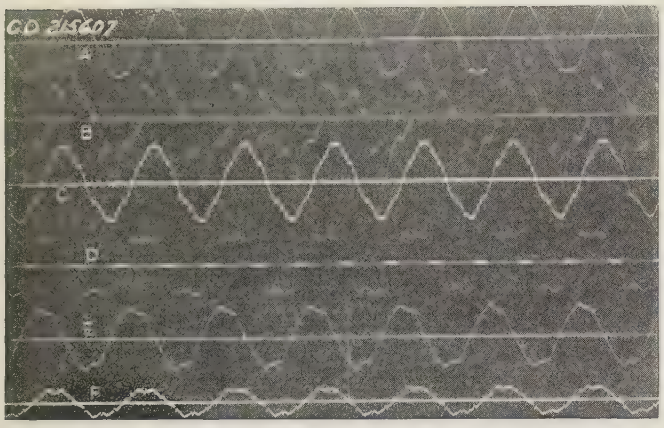


Fig. 9. Oscillogram for inverter operating at full load

D-c line volts 14,000; d-c line amperes 10.1; capacitance volts 395; load 550 volts, shop
A. Line voltage, constant potential lines
B. Line current, constant potential lines
C. Line voltage, constant current lines
D. Line current, constant current lines
E. Monocyclic capacitance voltage
F. Monocyclic inductance voltage

of the line current. In the 150 kw developmental apparatus a 2 ampere fuse would not be blown when used to short-circuit the 10 ampere lines operating at 15,000 volts. A 1-ampere 250-volt cartridge fuse, however, would be blown and would successfully rupture the short circuit on a 15,000 volt circuit. It is also possible to short the 15,000 volt d-c circuit with a standard knife switch, and then open the switch; no appreciable arc is formed across the switch blades when opening a circuit normally operating at 15,000 volts. The reason for this lies in the fact that the monocyclic network requires an appreciable time to restore the voltage after operating at short circuit. This will be discussed more fully later. Opening and closing a knife switch across a 15,000-volt constant-current circuit makes a very impressive demonstration because of the absence of any sign of distress, of either a transient or steady nature.

Commutation

In a constant potential inverter it is necessary to advance the phase of the grid excitation and therefore of the current by the angle desired for commutation. In a constant current inverter operating through a monocyclic network the amount and phase position of the current in the inverter is determined by the voltage on the constant potential side of the monocyclic network and cannot be shifted. In order to obtain a commutating voltage the phase of the grids of the inverter tubes is retarded slightly. This causes the monocyclic network to advance the phase of the voltage on the constant current side in order to prevent a shift of the current in response to the change of the grid excitation.

In this manner any desired phase advance of the voltage may be obtained on the constant current side of the monocyclic network for commutation purposes. This grid phase adjustment to obtain commutation may readily be made while the inverter is operating as a short-circuited rectifier. The commutating voltage is rather sensitive to a phase change of the grid excitation of the inverter tubes, but once this adjustment is made it need not be changed unless a different operation is desired. The grid phase adjustment for commutation, of course, determines the power factor at which the inverter operates, because the phase relation of the current on the constant potential side of the monocyclic network shifts in response to the phase shift of the voltage on the constant current side.

When the inverter is supplying a load of definite impedance characteristics such as induction motors or lamps, no adjustment of the grid phase is necessary. This adjustment is necessary only when the inverter is operating in parallel with synchronous generators of appreciable size.

When the inverter is operating as a short-circuited rectifier and there is no commutating voltage, the current on the constant potential side of the monocyclic network is small. This current would be zero were it not for losses in the monocyclic network and the harmonic currents introduced by the inverter tubes. An oscillogram of this line current at short circuit is shown in figure 7. As the grids are shifted to obtain a commutating voltage, the voltage across

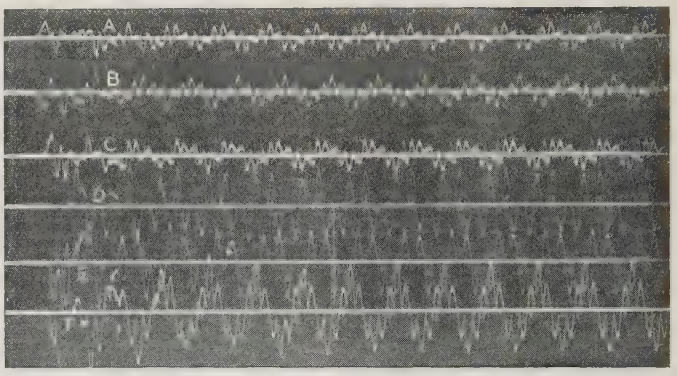


Fig. 10. Starting transients in inverter when full voltage is applied to the monocyclic network with the d-c lines short-circuited; full commutating voltage

D-c line volts 0; d-c line amperes 9.5; capacitance volts 475; supply, short circuit
A, B, and C. Line current, constant potential lines
D, E, and F. Line current, constant current lines

the monocyclic capacitances rises and the voltage across the monocyclic inductances decreases. These voltages serve as a convenient measure of the commutating voltage.

With the rise in the commutating voltage, there

appears a wattless component of current of fundamental frequency on the constant potential side of the monocyclic network. This condition is shown in the oscillogram of figure 8 where the inverter was operating as a short-circuited rectifier, but was adjusted for full commutating voltage. It is evident from an inspection of the oscillograms of figures 7 and 8 that there is a large harmonic component of current in the constant potential supply lines.

A glance at figure 4 shows that the harmonic component of the currents in lines A', B', and C' must pass through the capacitance and into the constant potential lines A, B, and C, while the fundamental component of the constant current at no load may be supplied by the inductance and capacitance. As the reactor voltage decreases and the capacitor voltage rises, to furnish commutation, an increasing component of wattless current of fundamental frequency is circulated in the supply lines of the constant potential side. When the load on the inverter is increased by raising the d-c supply voltage, a power component of current of fundamental frequency appears on the lines on the constant potential side of the monocyclic network. This power component of current on the constant potential side corresponds to a power component of voltage on the constant current side of the monocyclic network. This condition is illustrated in figure 9, which is an oscillogram of the inverter operating at full load.

A comparison of the oscillograms of figures 8 and 9 shows that there is an approximately constant component of harmonic current in the constant potential lines. These harmonic currents are not affected appreciably by the load, and are affected only slightly by the commutating voltage.

The wide variation of wave shape is attributable to varying components of the fundamental wave. It is unfortunate that so large a harmonic current exists at no load, but this is not a normal operating condition. At full load the wave shape has the same harmonics and the same telephone interference factor as a 6 phase rectifier, although the appearance of the wave is quite different because of the phase displacement of the harmonics with respect to the fundamental caused by the monocyclic network.

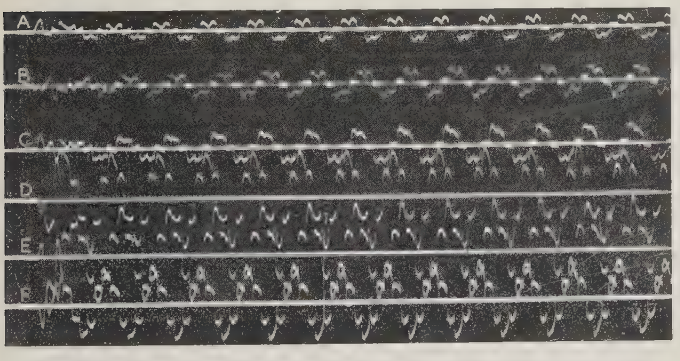


Fig. 11. Starting transients in inverter when full voltage is applied to the monocyclic network with the d-c lines short-circuited; inverter adjusted to seize full load

D-c line volts 14,200; d-c line amperes 10.1; capacitance volts 538; supply, rectifier
A, B, and C. Line current, constant potential lines
D, E, and F. Line current, constant current lines

Transient Conditions

It is very fortunate and somewhat surprising that the presence of the large inductive and capacitive reactances in the monocyclic network causes no undesirable transient conditions. A thorough oscillographic study of the transient conditions does not reveal any conditions under which the current or voltage of any portion of the circuit approaches twice normal value.

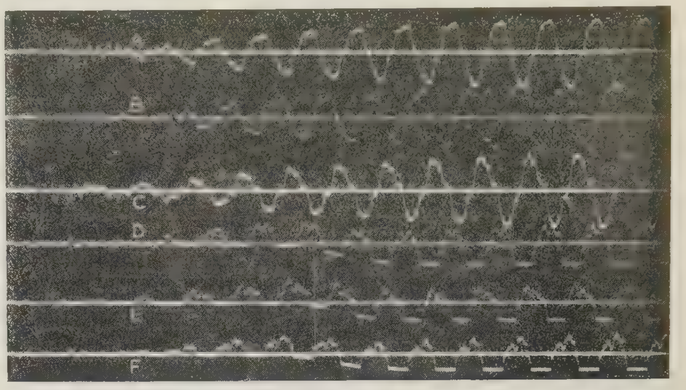


Fig. 12. Starting transients in rectifier when a-c supply circuit was closed; inverter operating through short circuiting tube and adjusted to seize full load

D-c line volts, 14,100; d-c line amperes 10.0; capacitance volts 360; load, inverter
A, B, and C. Line voltage, constant current lines
D, E, and F. Tube voltages, positive side

When voltage is applied to a monocyclic network connected to a 3-phase full-wave inverter short-circuited on the d-c side, the circuit behaves as an ohmic resistance during the period when the fields of the reactances are building up.

Figure 10 shows the current transients in both the constant potential lines and in the primaries of the transformers on the constant current side of the monocyclic network when full voltage is applied to the monocyclic network with the d-c lines short-circuited. The inverter grids were adjusted to give full commutating voltage, and the transformers were connected delta-delta.

The oscillogram of figure 11 shows the same currents when the inverter is switched on to the constant potential system, when adjusted to seize full load. Oscillograms taken at other points show that the steady state condition is established quickly and that no abnormally large currents or voltages occur. It should be noted in connection with figures 10 and 11 that these oscillograms were taken when the monocyclic network was switched on to a comparatively large system and that the connecting cables had no appreciable impedance.

The oscillogram of figure 12 shows the potential

across the constant current lines and across the tubes when the power was switched on the rectifier monocyclic network, with the inverter operating through a short-circuiting rectifier tube and adjusted to seize full load when the rectifier was connected. It is evident from figure 12 that the first 5 cycles are required to charge the monocyclic reactor fields and establish a commutating voltage. During this time the voltage of the d-c line is zero (the displacement of the straight portion of traces *D*, *E*, and *F* from the zero line is a measure of the voltage of the d-c line). An additional 3 cycles after the initial 5 are required to establish full load.

This slow response of the system to load changes is very favorable to the suppression of arcs formed on the d-c circuit. It is undoubtedly this characteristic that permits a knife switch short-circuiting the d-c lines to be closed and opened without causing an appreciable arc, although the d-c lines are operating at 15,000 volts.

The oscillograms of figures 13 and 14 show the same currents and voltages as figures 11 and 12, but under the transient conditions of switching a 1-ampere 250-volt cartridge fuse across the d-c lines. The fuse blows and successfully interrupts the 15,000 volt arc, although rated for only 250 volts. It is particularly interesting to note that the inverter output current in the constant potential lines does not decrease very greatly even during the time the d-c line voltage is considerably reduced. During the time of this disturbance the energy stored in the reactances of the monocyclic network serves as a reservoir to maintain the operation. It has not been possible to determine how well the inertia of the monocyclic network would have maintained the output during the transient disturbance if the load had been an ohmic impedance rather than an inverter feeding into a large system.

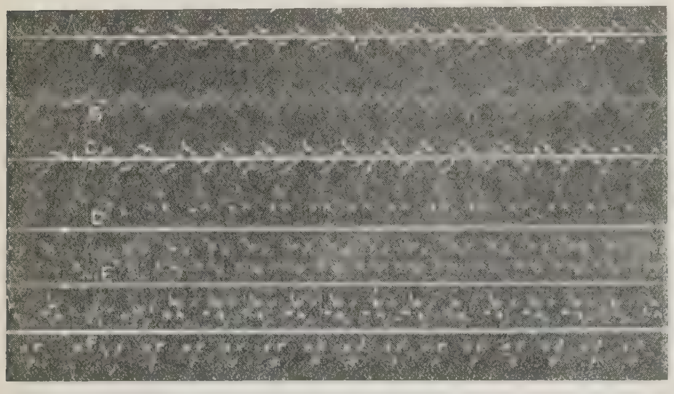


Fig. 13. Transients occurring when d-c line is short-circuited through a 1 ampere fuse

D-c line volts, 13,100; d-c line amperes 10.1; capacitance volts 440; load 550 volts, shop
A, B, and C. Line current, constant potential lines
D, E, and F. Line current, constant current lines

The traces shown as *D*, *E*, and *F* of figures 12 and 14 must be interpreted with some care because these tube voltages were taken with potential transformers, using a series capacitor to block the d-c component of the voltage. It is possible for this arrangement to introduce extraneous transient effects, but other sources of information indicate that the phenomena shown in figures 12 and 14 were present, although the time lag as shown on traces *D*, *E*, and *F* may have been exaggerated.

This inertia of the monocyclic network serves a very useful purpose in maintaining the inverter operation in case of tube failure. Unfortunately, high voltage rectifiers and inverters have been subject to occasional tube failures. In constant potential equipment this results in a serious condition and usually causes the protective equipment to disconnect the apparatus from the line and thereby results in an interruption. In a constant current rectifier or inverter employing a monocyclic network, a tube failure of a transient character does not cause the apparatus to be disconnected from the line, does not produce any harmful condition, and may not cause an appreciable interruption of service.

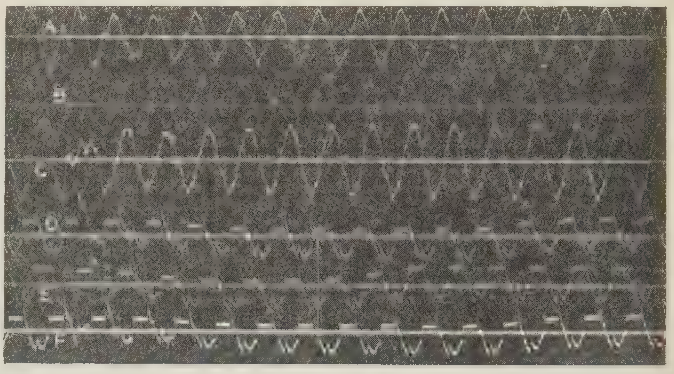


Fig. 14. Transients occurring when d-c line is short-circuited through a 1 ampere fuse

D-c line volts 12,200; d-c line amperes 10.1; capacitance volts 425; load 550 volts, shop
A, B, and C. Line voltage, constant current lines
D, E, and F. Inverter tube voltages, positive side

It has not been possible to catch a tube arc-back or loss of control on an oscillogram, but it has been possible to produce these conditions many times by the use of defective tubes. Almost invariably the apparatus will run through these tube failures with no appreciable interruption of the output.

Losses

The losses involved in converting constant-potential a-c power to constant current d-c power, or conversely, are about 1 per cent. It would appear possible, therefore, to convert an a-c transmission system to a d-c constant-current system and incur only a 2 per cent increase of the losses as based upon the power transmitted. A greater saving than this probably can be effected by the elimination of the wattless component of the current by the d-c transmission system.

In conclusion the authors would emphasize the stability and reliability promised by this new system of power transmission employing constant current rectifiers and inverters.

A Carrier Current Relay Installation

Operating experience obtained during 2 lightning seasons with an installation of carrier current relays on a New England power system is presented herewith. A résumé of the reasons for the choice of this type of protection also is given, and the relay and carrier current equipment is described.

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DURING the spring and early summer of 1933, the Turners Falls Power and Electric Company, together with the United Electric Light Company and the Western Massachusetts Electric Company, subsidiaries of the Western Massachusetts Companies, installed a system of carrier current controlled relay protection on approximately 105 miles of double circuit tower lines comprising that part of their 69 kv transmission system which is between the Cabot power station and the Agawam substation. The relays and associated equipment were installed on a total of 28 line terminals at 10 various stations, including one of the Holyoke Water Power Company's stations. A geographic sketch of the system involved is shown in figure 1, and in figure 2 is a schematic layout of the system.

The system involved is continuously interconnected with that of the New England Power Company on the north at Cabot station, by means of a 115-kv double line tap to the Harriman-Millbury line; and on the south to the Hartford Electric Light Company and other Connecticut companies, by a double circuit 69-kv line.

The relay scheme previously in use was a combination of balanced line power directional relays and balanced line directional ground relays, with relays for single line or double line operation. This scheme had several serious drawbacks, chief of which was the long time delay in clearing the line sections due to the high current and long time settings required for normal operation. The results of such long time settings were serious damage to the lines, and long interruptions to equipment when the lines were subjected to flashovers from lightning or other causes.

For the purpose of eliminating this recurring damage, several schemes were proposed:

1. Rebuild the lines to increase the insulation; or
2. Decrease fault currents; or
3. Reduce circuit breaker time by improvements in relays and methods of operation. The lines had already been equipped with high speed circuit breakers.

Of these 3 possible remedies, changing the relay scheme seemed to offer the most improvement for the money invested.

Two general schemes of relay protection were studied:

1. The application of distance type and high speed balanced line relays.
2. The application of high speed power directional relays with pilot wire or differential type of control.

Whatever scheme of relays was used, it would have to provide quick clearing time for both single line and double line faults, as past experience indicated that approximately 75 per cent of all lightning flashovers would involve both circuits.

Due to the peculiarities of the system in question, i. e., the combination of long lines and short lines with tap stations at various points, distance relays would not function entirely satisfactorily. During fault conditions instantaneous tripping of the circuit breakers at both ends of any line section could not be

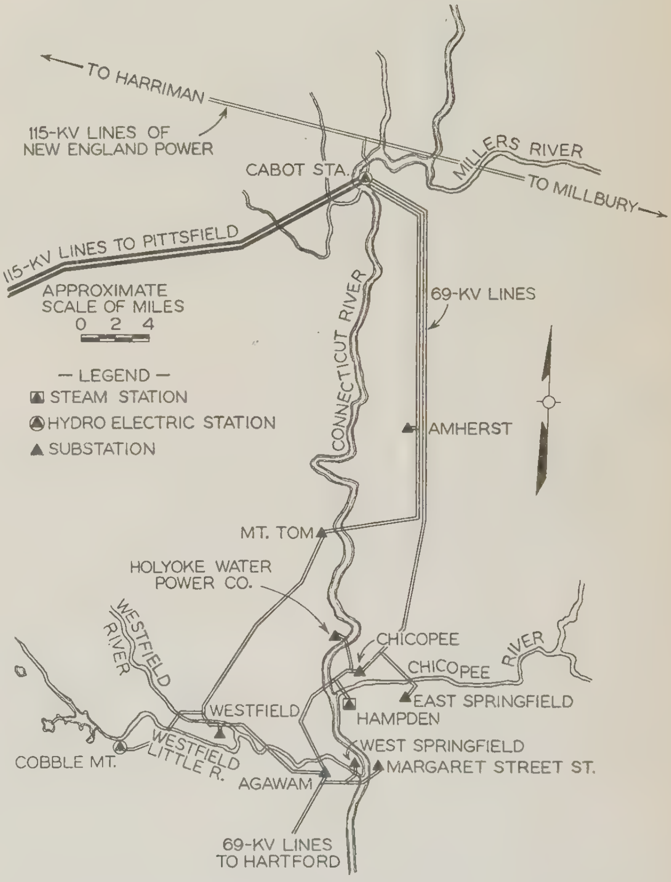


Fig. 1. The 69-kv system of the Turners Falls Power and Electric Company

A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted Oct. 22, 1934; released for publication Nov. 27, 1934.

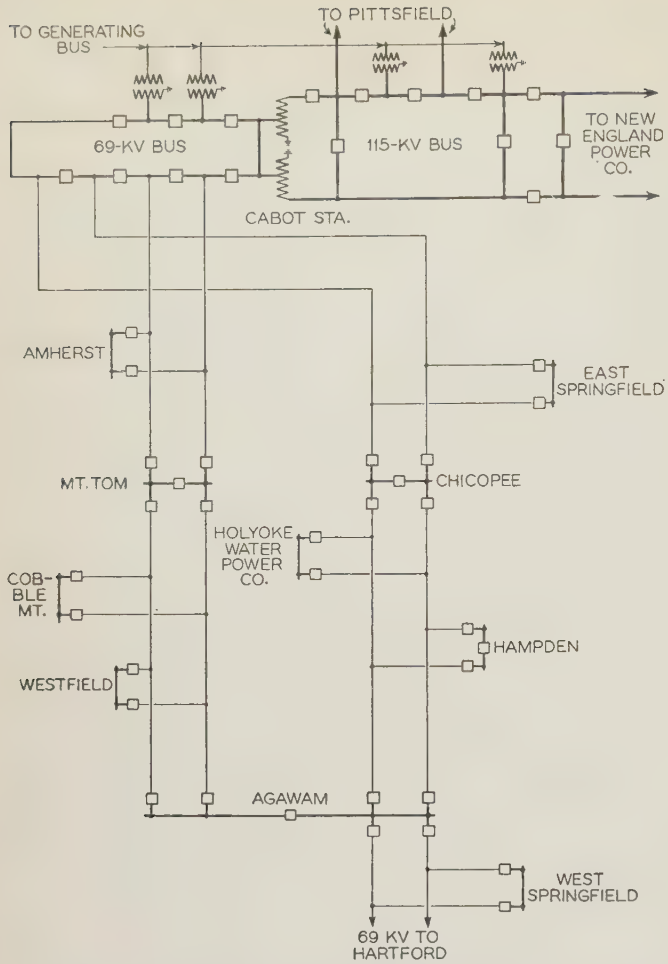


Fig. 2. Schematic diagram of the system of the Turners Falls Power and Electric Company

obtained. With distance relays in use on the Cabot-Mt. Tom lines, for instance, the minimum time for the clearing of a fault would be between 50 and 60 cycles and, for a fault in the vicinity of a tapped station, this time delay would occur at both ends. Conditions would be even worse were these relays applied to some of the other lines.

Carrier Current Equipment Proposed

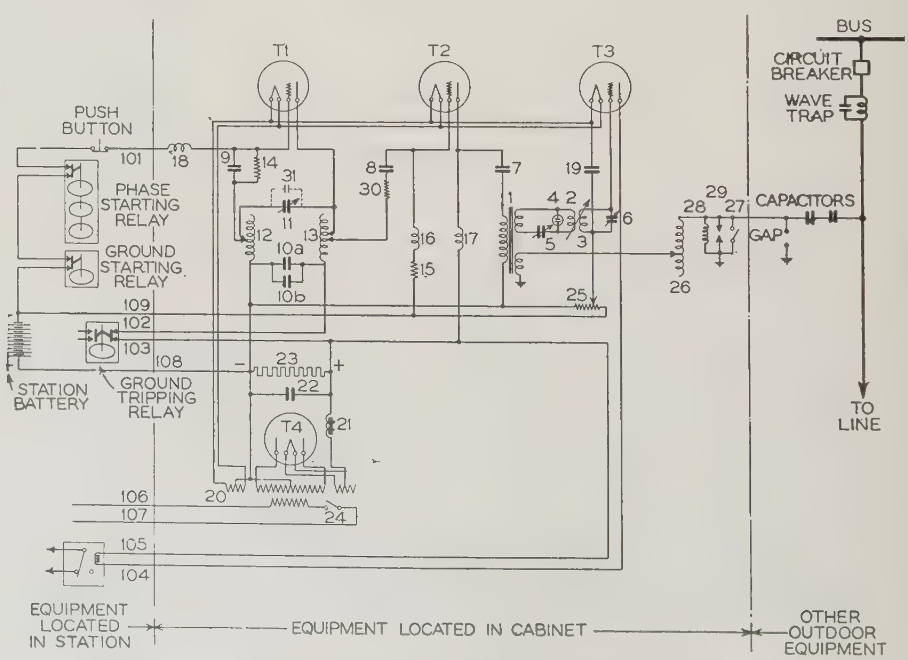
A study of the pilot wire or differential type of protection indicated that the straight pilot wire type of control was, due to the length of pilot wire conductors required, out of the question. Conductors owned by the communication companies were considered but it was decided to use apparatus under the control of the power company. By using carrier-current equipment, the pilot wire conductors themselves could be omitted and the conductors of the high voltage line used instead. The transmission of a carrier current signal would be required only during the existence of a fault on the system; and then only on those lines not involved in the fault. That is, the carrier current signal would be used to provide a locking-out of tripping relays on the good line rather than for the tripping of the faulted lines.

The relays in use on each line terminal would consist of special over-current relays coördinated with high speed power directional relays so connected that tripping would be obtained only for the condition of power flow into the line with no power flow out of the line. If, at any station, the flow of power was from the line to the bus, the relays would start a carrier signal which would be received practically instantaneously at the other terminals on the line and would operate relays to open the tripping circuits of all the oil circuit breakers on that line, thus preventing the opening of such breakers.

The relays, both phase and ground, at both ends of the lines and at all tap stations would be set for the same time, approximately 8 cycles. This time setting would depend entirely upon the time required

ITEM NO.	NAME
1.	Output transformer
2.	Receiver primary coupling coil
3.	Receiver secondary coupling coil
4.	Receiver protective neon glow lamp
5.	Receiver primary variable condenser
6.	Receiver secondary variable condenser
7.	Power amplifier plate blocking capacitor
8.	Power amplifier grid coupling capacitor
9.	Oscillator grid capacitor
10a.	Oscillator plate blocking capacitor
10b.	Oscillator plate blocking capacitor
11.	Oscillator variable capacitor
12.	Oscillator grid coil
13.	Oscillator plate coil
14.	Oscillator bias resistor
15.	Power amplifier grid resistor
16.	Power amplifier grid-choke coil
17.	Power amplifier plate choke coil
18.	Oscillator grid choke coil
19.	Receiver bias by-pass condenser
20.	Power transformer
21.	Rectifier filter reactor
22.	Rectifier filter capacitor
23.	Rectifier voltage divider
24.	Power supply switch
25.	Receiver bias potentiometer
26.	Tuning inductance
27.	Grounding switch
28.	Drainage coil
29.	Protective spark gap
30.	Power amplifier excitation resistor
31.	Auxiliary tank capacitor
T-1	Master oscillator tube, type 210
T-2	Power amplifier tube, type 210
T-3	Receiver tube, type 210
T-4	Full wave rectifier tube, type 83

Fig. 3 (below) Schematic diagram of carrier current equipment



for the carrier sending relays and the lock-out relays to operate.

No extensive calculations would be required for determining the setting for the carrier current relays. Distance relays, however, involve extensive calculations which become quite complicated if ground fault protection is required.

Potential for directional relays on carrier current equipment is required only for indicating direction, not reactance or distance measurement, and may be taken from low voltage sources. Thus, high voltage potential transformers are not needed except where required for directional ground protection.

After extensive studies of the general schemes mentioned above, the scheme of carrier current pilot control, with the line conductors supplying the carrier channel, was adopted. High speed power directional and directional ground relays were selected for the relay equipment.

A description of the schemes finally selected for use at the various stations is naturally divided into 2 parts, as follows:

1. Carrier current equipment
2. Relay equipment

The equipment will be described in this order.

Carrier Current Equipment

The carrier current set is divided into 3 parts, as follows (refer to figures 3 and 4):

1. Rectifier shelf (bottom of cabinet).
2. Transmitter and receiver shelf.
3. Line tuning panel and protective devices (top of cabinet).

Rectifier. The 500 volt d-c power supply, for operation of transmitter and receiver, is obtained from a full wave tube rectifier, using a step-up transformer and a type 83 rectifier tube, operating from a constant source of a-c potential, 115 volts, and approximately 60 cycles, obtained from a small dynamotor operating on the station battery. Each dynamotor is capable of supplying the power requirements for 2 carrier current sets. A spare unit with proper throw-over relays is provided for emergency use in the event the regular set fails.

Transmitter. The master oscillator of the transmitter uses one of the standard oscillating circuits in which the frequency calibration is obtained by a variable air condenser. The oscillator is started by removing the 125 volt negative bias which is normally applied to its grid. One step of amplification is used to increase the output of the transmitter.

Receiver. The receiver consists of 2 loosely coupled tuned circuits using only one tube as a grid biased detector.

General. The protective devices located in the outdoor cabinet of the carrier current set consist of grounding switch 27, drainage coil 28, and spark gap 29. The line tuning panel, 26, is used to tune the inductance of the antennae system for maximum output at any frequency.

One phase coupling and ground return is used for the transmission of the carrier signal. The connections between the outdoor cabinet and the capacitors consist of a high grade rubber insulated number 6 solid copper wire, mounted on a minimum number of vertical insulators. Two 46 kv, 0.001 microfarad capacitors connected in series are used on the 69 kv circuits. They are mounted adjacent to each other on 46 kv insulators. These capacitors are similar to others already in use for ground relay potential.

In addition to using the capacitors for carrier current relaying, at some locations they are also used in conjunction with potential devices to obtain a line potential for synchronizing purposes. For this use, an auxiliary capacitor, 0.002 microfarad, and a carrier frequency choke are required.

A carrier frequency line trap consisting of an inductance coil and condenser is installed in series with the phase wire used for the carrier current channel, and is located between the tap to the coupling capacitors, and the bus at each station. This trap is necessary to keep the high frequency current in the section of line where it belongs, and to prevent external faults from short-circuiting it.

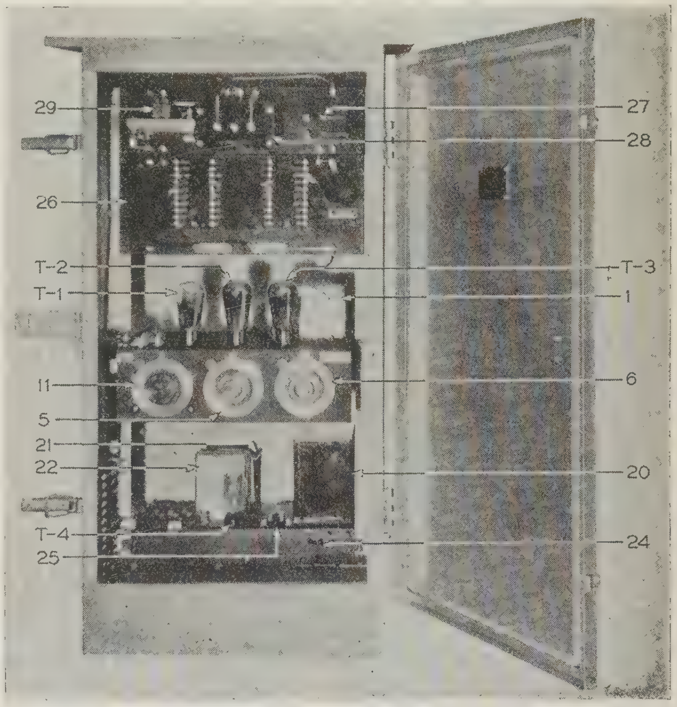


Fig. 4. Outdoor carrier current cabinet

Relay Equipment

The relay equipment proper has 2 functions to perform, as follows:

1. To start transmission of blocking signal when power flow is from line to bus.
2. To trip the oil circuit breaker for line faults.

Two different schemes were finally chosen for use, one scheme being used at the sectionalizing stations, Cabot, Mt. Tom, Chicopee, and Agawam, while the second scheme was used at the remaining stations,

namely, Amherst, Cobble Mountain, Westfield, Hampden, Holyoke, and East Springfield. The difference between the 2 schemes is in the type and connections of the phase relays used for tripping.

In general, 2 phase relays and 2 ground relays are used, one relay of each having normally closed contacts that open on power flow from the line into the bus. Another set of relays of the conventional type are used to complete the tripping circuit to the oil circuit breaker. The connections from the current transformer to the various relays in use at a sectionalizing station are shown in figure 5. The 3 pole,

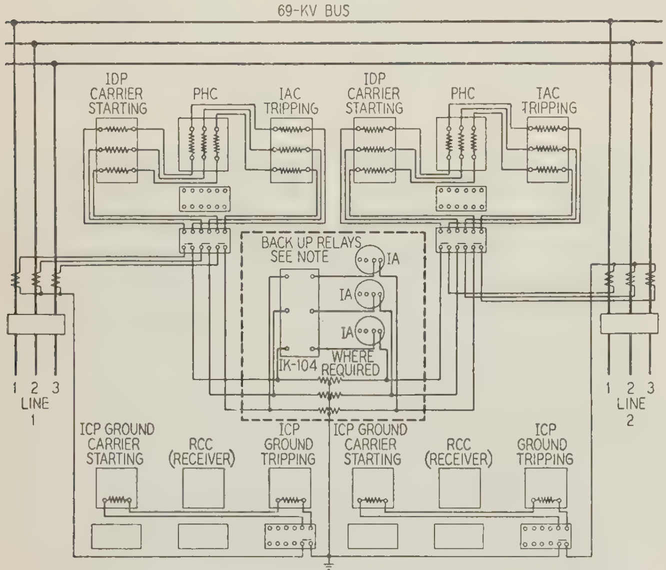


Fig. 5. Connection diagram for current transformers and relays controlling carrier current equipment

Note: Back-up relays and midpoint autotransformer located on separate panel

type *PHC* plunger relay contacts are used to remove voltage restraint from the power directional type *IDP* relay, which is used as the carrier current starting relay.

The tripping of the oil circuit breaker is accomplished by the type *IAC* relays through the contacts of the type *IDP* relay. The control connections are shown in detail in diagram of figure 6. The circuit for the carrier starting relays is through the contacts of the phase *IDP* relay and ground *ICP* relay in series.

Provision is made for manual test of the complete carrier apparatus by means of a push button in the circuit to the grid of the master oscillator tube. This provides a complete test of all sending and receiving apparatus, including a check of the tripping circuit.

The receiver relay is of the d-c polarized type, operating on approximately 2.5 milliamperes in the operating coil. The polarizing coil is constantly energized at 125 volts direct current. The contacts are of the single pole double throw type. A holding coil is provided to hold the contacts in the normally closed position in case tripping current is flowing, thus preventing operation of the relay by a stray carrier signal and burning of the contacts. The normally closed contacts of this relay are in the tripping circuit and operation of this relay by a received carrier signal prevents tripping of the circuit breaker. Suitable connections through the normally open contact provide for a visible and audible signal when the relay is in the operated position.

The scheme at the tap stations substitutes a type *IDP* for the 3 pole *IAC* relay, to provide for the tripping functions through circuit closing contacts, when the power flow is into the line. The phase carrier starting relay operates to open its contacts when the power flow is into the bus in either case.

The ground relay protection functions in a similar manner, except that the tripping relay has an additional set of contacts which are normally closed. This set of contacts is in the plate circuit of the master oscillator tube and prevents operation of the transmitter when the tripping ground relay operates, even though the phase power directional relay indicates a resultant power flow into the bus.

Back-up overload relays are installed at certain locations, namely, Cabot, Mt. Tom, Cobble Mountain, Agawam, Hampden, Chicopee, and East Springfield. They are connected as shown in the dotted insert of figure 5.

The photograph in figure 7 shows front view arrangements of the panels as finally used. The relays for one line are on the top section and the second line on the bottom section of the panel.

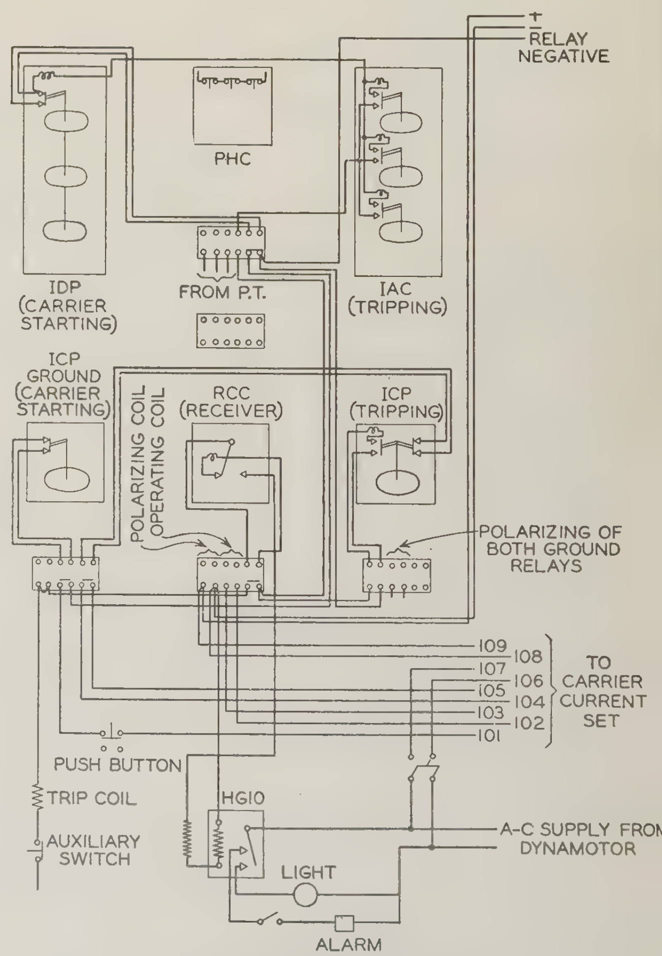


Fig. 6. Control connections for relays used for carrier current protection

Installing and Adjusting

The procedure followed in installing and adjusting the carrier current equipment is described briefly as follows.

The carrier current apparatus was set up and put in working order, and all adjustments and settings made before the relays controlling this equipment were connected to the current transformers.

On this system, 2 parallel circuits were available in each section of line. The carrier current equipment on one line was used by the testing crew for communication purposes between the several stations on the section while final adjustments were being made on the equipment of the remaining line. For this purpose a small telephone unit, consisting of a telephone hand-set and some auxiliary equipment was used to modulate the transmitted signal by talking. All of the preliminary adjustments, except setting the carrier frequency traps, were made with the line in service.

Final tests and adjustments on the remaining line were made as follows.

An arbitrary value of frequency was selected for trial. The line was removed from service, but not grounded. Having the section of line open at all points was the equivalent to having perfectly tuned traps at these locations for all frequencies. Thus, the effects of the wave traps were neglected on these preliminary tests. A signal was transmitted, the frequency of which was varied in steps of 1 kilocycle, over a range of approximately 10 kilocycles either side of the selected value. The value of frequency was determined by a wavemeter located at one station.

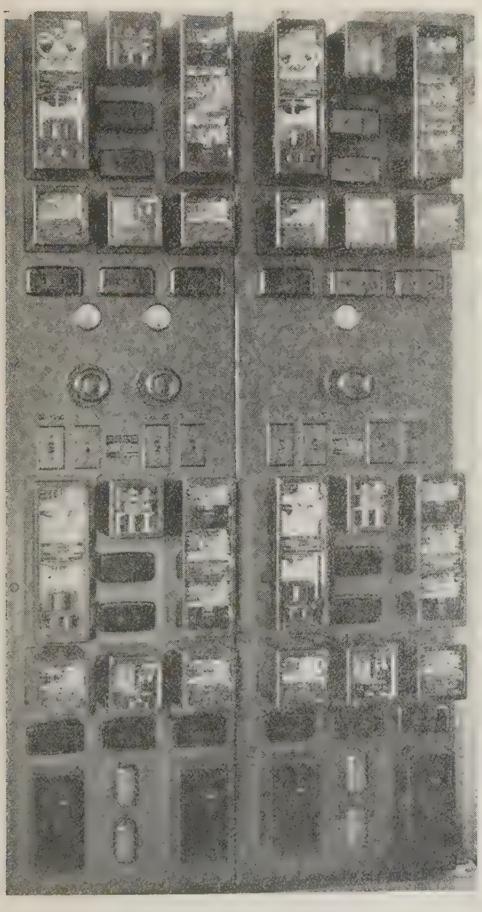


Fig. 7. Front view of relay panels

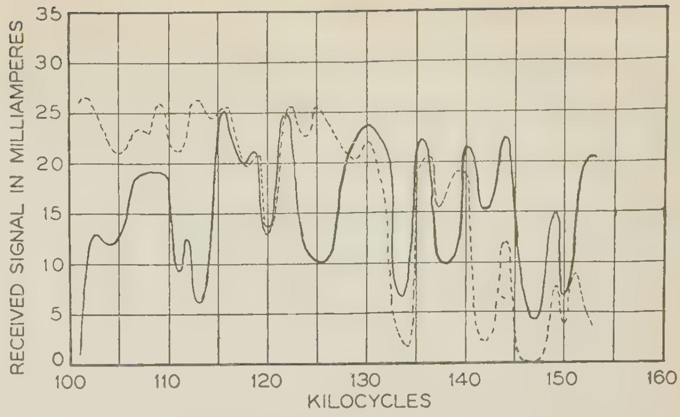


Fig. 8. Open line characteristics of the entire Mt. Tom-Agawam line; signal sent from Mt. Tom

Solid line—Signal received at Westfield substation
Dash line—Signal received at Agawam substation

The sets at the remaining stations on the line section under test were tuned to the frequency of the first set, by having both sets transmit a signal at the same time. With a telephone receiver connected to the receiver circuit of the second set, a beat note was audible. The frequency of the second set was brought into synchronism with the first by lowering the pitch of the beat note until it disappeared. The output was tuned to a maximum value by changing taps on the tuning inductance coil. The receivers were tuned for a maximum received signal. Complete readings were recorded for each value of transmitted frequency.

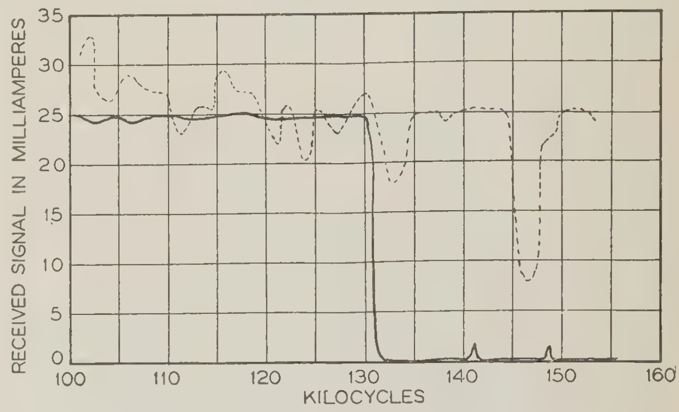


Fig. 9. Open line characteristics of the Mt. Tom-Agawam line; signal sent from Mt. Tom

Solid line—Signal received at Cobble Mountain, Agawam tap open at Westfield
Dash line—Signal received at Cobble Mountain, Agawam tap closed at Westfield

These data, when plotted, gave a curve of the open line characteristics for transmission of the high frequency currents over the entire line. It was also necessary, in order to obtain proper relaying under certain operating conditions where transmission lines may be sectionalized, to obtain a similar curve for various portions of the line.

The final frequency which was selected from a

study of these curves was in the center of a flat topped broad portion of the curve where a good signal was obtained at all stations under all operating conditions. This precaution was necessary so that extreme changes in temperature would not affect the operation of the equipment.

Typical curves of open line characteristics on the Mt. Tom-Agawam entire line are shown in figure 8. Figure 9 shows the change in received signal at Cobble Mountain when this line was sectionalized at Westfield, leaving the line between Mt. Tom and Cobble Mountain in service. The frequency finally selected was 116 kilocycles. The wave traps at all stations on this line section were then set for this frequency.

Additional data were taken with the line still out of service, but with the phase to which the carrier current equipment was coupled grounded on the station side of the wave trap; and also, with the line in service.

When this equipment was ready for service, the temporary telephone equipment was changed over to the finished line, and a similar set of tests made in the line which had been used for communication.

Difficulties

A continuous signal was received at just one station on one section of line. This was due to a faulty fuse clip in the d-c supply leads removing a bias from the detector tube, allowing this tube to pass current, which in turn picked up the receiver relay.

Later in the season there was some difficulty on 1 or 2 sections of line due to temperature changes affecting the calibration of the master oscillator circuit, and shifting of the line characteristics sufficiently to eliminate reception of the carrier current signal. These shifts in frequency were probably in the order of 1 to 2 kilocycles. The carrier current sets were tuned to a frequency on the edge of a peak on the line characteristics curve, and the shift due to temperature changes, though slight, were sufficient to cause trouble. In most cases, the tuning band of good reception was broad enough to allow slight shifts in frequency, and still get good reception at all temperatures. In one case, it was necessary to shift to an entirely different frequency band.

Trouble was caused by very heavy rain storms or sleet causing sufficient leakage on lead-in wires and supporting insulators so that no signal was received. The original lead-in connections were bare copper wire. By using an insulated lead-in conductor, vertical mounting of supporting insulators, and rain shields, these conditions were improved and no further trouble is expected.

Maintenance

The carrier current sets are checked at 7:15 a.m., 3:15 p.m., and 10:30 p.m. by each station operator sending a signal in a predetermined order. Failure to receive a signal at any point is immediately checked by the operators themselves. They are instructed how to change tubes in the carrier current sets, check relay contacts for proper position, and, in general, to note whether the set is failing to send out the signal or the set at the other end failing to receive the signal. Cases which require more knowledge than this are reported at once to the proper parties for investigation.

As a further assistance to the operators, and for use in checking the operation of the carrier current equipment, ammeters with a 50 milliampere range and mounted on test plugs are available for measuring the received signal. The operators are instructed to take readings when the routine tests are made, or to observe that the received signal does not drop below a minimum of 10 milliamperes. This is considered the lowest desirable value, although the receiver relays will operate at 2.5 milliamperes.

The sets are given a general inspection late in the fall and a more detailed inspection in the spring just before the lightning season.

Normally, tubes are allowed to run until failure takes place, except on the inspection just before the lightning season when all tubes of a doubtful nature are replaced. Tube replacements have not been excessive and therefore it has not been considered necessary to keep individual tube records any more than one would of the Mazda lamps in his house. The type 210 tube life, as far as can be determined, is about a year. These tubes have a rated life of 1,000 hours, but last approximately 8,000 hours. This is due to the fact that while the tube filaments are lighted at all times, they only pass plate current intermittently. The type 83 tubes are somewhat shorter lived, probably averaging 6 to 8 months. A complete replacement of tested type 83 tubes and a 50 per cent replacement of type 210 tubes are kept

Table I—Number of Relay Tripping Operations

	1933	1934 to Oct. 1	Total
Total number of correct operations	113	164	277
Incorrect operations	10	22	32
Failures to operate	9	2	11
Total operations, including failures	132	188	320
Per cent correct operations	85.6	88	86.6

Table II—Single Line and Double Line Operations

Cause and Type of Fault	1933	1934 to Oct. 1	Total
Lightning			
Double line faults	14	17	31
Single line faults	9	8	17
Total faults	23	25	48
Total line sections in trouble	37	42	79
Other Causes			
Double line faults		2	2
Single line faults	6	9	15
Total faults	6	11	17
Total line sections in trouble	6	13	19
Total—All Causes			
Double line faults	14	19	33
Single line faults	15	17	32
Total faults	29	36	65
Total line sections in trouble	43	55	98

at each station at all times. Tubes removed are gathered into central points and tested every 2 to 3 months.

Operation and Results

In 1933, the relays on the first section of line went into service about the 15th of May, and the last about the first of August.

Since that time, the following number of relay tripping operations shown in table I have occurred.

A total of 8 causes for the incorrect operations and failures to operate have been located and corrected. To date, the causes of only 2 incorrect operations are listed as unknown.

The faults causing these circuit breaker operations were divided between single line and double line interruptions as shown in table II.

Out of 79 line sections tripping out due to lightning flashovers during the 1933–34 seasons, only one developed trouble which prevented the line from being immediately returned to service. This interruption was caused by a mechanical failure of an insulator which allowed one conductor to fall to the ground. The fast relay and circuit breaker clearing time prevented the copper conductor from being damaged.

Tripping of the oil circuit breakers during surging between this system and the systems of adjacent companies, has, up to the present time, been prevented with the installation of this equipment.

The fast relay tripping time, together with the high speed oil circuit breakers, has materially reduced the extent of the damage to the transmission lines, and has reduced the extent of voltage disturbances and surges to a minimum.

This installation of relay equipment has operated in an entirely satisfactory manner and has justified its cost in the results so far obtained.

Ultra-Short Waves in Urban Territory

This paper extends a previous paper on the investigation of ultra-short wave propagation, to include transmission within a built-up region together with a consideration of the additional problems introduced by man-made interference. Tests were made using both a fixed transmitter with mobile receiver, and a mobile transmitter with a fixed receiver.

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EXPERIMENTAL data on the propagation of ultra-short waves in urban territory obtained within the city of Boston, Mass., at a frequency of 34.6 megacycles per second are presented in this paper. The paper is a sequel to an earlier paper "Ultra-Short Wave Propagation,"[1] which dealt mainly with transmission across open country. Mass plots of the field strength as a function of distance both for transmission from a fixed location to a mobile receiver and from a mobile transmitter to a fixed location show that the mean field strength varies inversely as the square of the path length, which is the same variation as would be expected for level terrain in the absence of buildings. The same data are presented also in the form of field strength contour maps. Some effects of local conditions that cause deviations of individual points from the mean curve are discussed on the basis of experimental evidence here presented. The data presented were obtained during the summer of 1933.

These data are interpreted on the basis of the same physical picture that has been established for open country. The present data preclude interpretation upon the basis employed by earlier investigators of ultra-short wave propagation through urban areas. Types of interfering noise are discussed. For reception at the mobile terminal, automobile ignition noise was found to be the most objectionable.

Apparatus

Both terminals employed vertical half-wave antennae which were connected to balanced circuits by means of symmetrical 2-wire transmission lines. At the fixed locations unloaded antennae were used; at the mobile terminal, in order to limit their heights to 8 feet above the ground, the antennae were loaded so that their lengths were reduced to about a quarter wave length (see figure 1).

The transmitter consisted of an electric oscillator employing 2 75-watt tubes operating in push-pull relationship. At the fixed location where ample power was available, the transmitter was capable of producing 1 ampere (measured by a Weston type 425

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1. For all numbered references see list at end of paper.

thermoammeter at the current maximum) of 100 per cent modulated carrier in its antenna without undue distortion. The mobile transmitter, which used a dynamotor for tube plate supply, was capable of producing the same current in its antenna. This corresponds to about 6 decibels less power because of the shorter antenna length.

The measuring set was of the double detection type with balanced high frequency circuits, push-pull first detector, and calibrated intermediate frequency attenuator. The set was similar to that described previously by Friis and Bruce.[2] This receiving equipment was calibrated in absolute units by the method described in the appendix. A mechanism for recording the field strength was attached to the measuring set; this consisted of a roll of paper that could be driven either by clockwork or by the rear wheels of the truck. The position of the recording pen was controlled by the setting of a manually operated variable attenuator. Samples of the type of record obtained are shown in figures 6 and 7.

Locations

The radiator for the fixed transmitter was supported by a 50-foot pole above the roof of a 7 story building at the corner of Berkeley and Stuart streets in the business section of Boston. The building is about 90 feet high, making the center of the antenna about 130 feet above the ground. Thus, the antenna was higher than most of the buildings of the city though it was lower than a few buildings nearby.

The antenna for the fixed receiver was supported by a 20 foot pole from the middle of the highest ridge of a gabled building, making the center of the antenna about 80 feet above the street level. This building is situated on the side of a slight slope in a fairly heavily wooded territory, on Seaverns Street near Center Street.

Field Strength Measurements: Transmitter at a Fixed Location

With a current of 1 ampere in the half-wave antenna above the building at Berkeley and Stuart

Fig. 1. Mobile receiving equipment

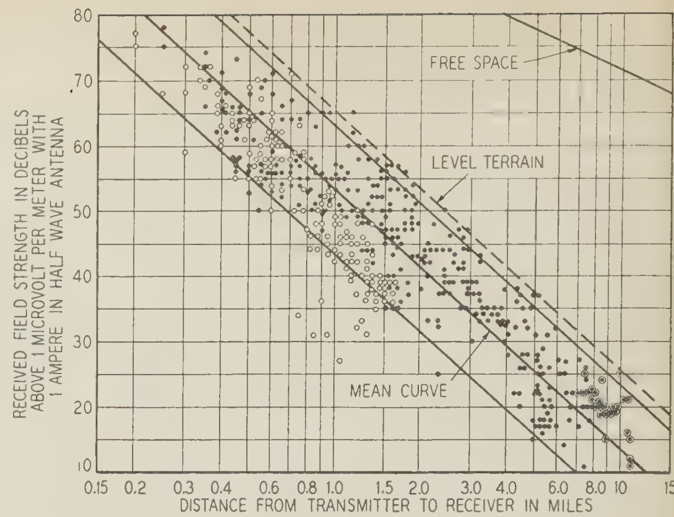


Fig. 2. Mass plot of field intensities measured at various distances from the transmitter at Berkeley and Stuart streets in Boston

The values corresponding to distances less than 2 miles represent field strengths averaged over $^1/_{10}$ mile intervals, while those for greater distances represent averages over $^1/_2$ mile intervals. The open circles indicate fields in the high building area; the solid circles indicate fields in the residential district. Residential points outside the city limits have been enclosed in circles

streets and with the receiver in the truck, field strength measurements were made along various routes throughout Boston. Since the antenna was in free space in so far as radiation resistance is concerned, this current corresponds to a radiated power of 73 watts. The data thus obtained have been averaged by $^1/_{10}$-mile intervals when the average radial distance was less than 2 miles and by $^1/_2$-mile intervals for greater average distances. A plot of these data is shown in figure 2. The points lie approximately on an inverse-square-of-distance line with deviations ranging up to about ± 10 decibels. An effort has been made to separate the points taken in the high building area. These points (shown as open circles) lie somewhat below the others with a few particularly low field strengths. The lowest field strengths in the business district were measured along the shore near Charles River Dam and near State Street on Atlantic Avenue. The field strengths in the business district would be expected to be lower because of the presence of the high buildings. The lower residential field strengths correspond to the region beyond Chestnut Hill.

When attempting to interpret the results of the mass plot of figure 2 a natural method would be to assume transmission as in free space plus an additional attenuation due to the proximity of the earth and obstacles above the earth's surface. The simpler case of transmission over level terrain in the absence of obstacles will be considered first.

It has been determined experimentally that the propagation of ultra-short waves over unobstructed paths follows the laws of optics[1,3] so that the resultant field is composed of a well defined reflected wave superposed upon a direct wave. Consequently for propagation over level terrain, the explanation is as follows (figure 3): Energy is propagated from a

transmitter at A, at a height of h_1 above the ground, to a receiver at B, at a height of h_2 above the ground, both directly, as represented by r_1, and by reflection at G, as represented by r_2, the distance between transmitter and receiver being represented by d. For the practical case where h_1 and h_2 are small compared with d, the reflected wave impinges upon the ground at nearly grazing incidence, so that a negative reflection coefficient, the magnitude of which is unity for ordinary ground (not water) is obtained. This results in the field at B being the difference between 2 vectors of equal magnitude and differing in phase by an amount corresponding to the difference in path lengths, r_2 and r_1. For the case under consideration,

$$r_2 - r_1 = 2h_1h_2/d \tag{1}$$

and the angle between the vectors is

$$2\pi(r_2 - r_1)/\lambda = 4\pi h_1h_2/\lambda d \tag{2}$$

Except in the immediate proximity of the transmitter, this angle is small and the resultant field is

$$E = E_0\,(4\pi h_1h_2/\lambda d) \tag{3}$$

where E_0 is the free space field.

To be more exact, the magnitude of the negative reflection coefficient of the ground is $1 - 2\epsilon\,(h_1 + h_2)/d\sqrt{\epsilon - 1}$ for vertical polarization and $1 - 2(h_1 + h_2)/d\sqrt{\epsilon - 1}$ for horizontal polarization, making the corresponding values for the received fields,

$$E_0\,\frac{(4\pi h_1h_2)}{\lambda d}\sqrt{1 + \frac{\epsilon^2(h_1 + h_2)^2\lambda^2}{(\epsilon - 1)\pi^2h_1{}^2h_2{}^2}} \tag{3a}$$

$$E_0\left(\frac{4\pi h_1h_2}{\lambda d}\right)\sqrt{1 + \frac{(h_1 + h_2)^2\lambda^2}{(\epsilon - 1)\pi^2h_1{}^2h_2{}^2}} \tag{3b}$$

respectively, instead of as in equation 3. When the lower of the 2 antennae is more than a couple of wave lengths off the ground, the radicals are substantially unity. For the case under consideration it would be more accurate to refer to expression 3*a* as the theoretical formula, but lack of knowledge of the magnitude of the dielectric constant and antenna heights that apply would introduce unnecessary uncertainty if the results were referred to this formula. It might be remarked that neglecting the presence of buildings and referring all heights to the local street level, the radical represents an increase of 13 to 20 decibels for vertical polarization in the cases under consideration.

Now since

$$E_0 = 60\pi HI/\lambda d \tag{4}$$

the resultant field becomes

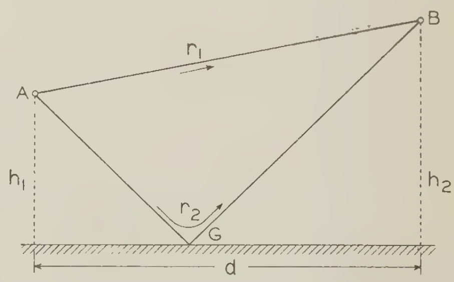
$$E = 240\pi^2 HIh_1h_2/\lambda^2d^2 \tag{5}$$

If I is in amperes, d in meters, H the effective height of the antenna, and λ the wave length in the same units, E_0 is given in volts per meter.

Equation 5 shows that the field over level terrain is inversely proportional to the square of the distance from the source. Since distance appears in this equation only as a factor and not as an exponent, the reduction with distance of the field strength of ultra-short waves over level terrain is independent of wave length, polarization, dielectric constant, etc., as all of these quantities cancel in the ratio of the field strength at one point to that at another. The absolute magnitude of the field strength is proportional to the frequency for the same radiated power and antenna heights. If the antenna heights are sufficiently low, the field is also dependent upon the polarization and ground constants as indicated by expressions 3*a* and 3*b*.

Data presented in figure 8 of reference 1 show that at a frequency of 69 megacycles per second the field strength variation with distance follows approximately the inverse-square relationship for a range of from 2 to 90 kilometers. In fact, the best straight line through these data agrees with the numerical values obtained from equation 5 well within the accuracy of the experimental data. While undoubtedly at the greater distances the field suffers additional attenuation above that shown by equation 5 due to the curvature of the earth, such additional attenuation evidently takes place at distances beyond those employed in any of the authors' experiments. Experiments designed to test the validity of this equation now are being conducted at Deal, N. J., and data obtained to date confirm it both as to absolute value and variation with terminal heights and wave length for horizontal polarization within the range $2 < h_1 < 25$, $2 < h_2 < 25$, $2 < \lambda < 17$, $d = 9{,}420$, and 26,300, all measured in meters.

Fig. 3. Diagram illustrating wave propagation over level terrain



The experimental confirmation of this formula for these distances indicates that the earth's curvature is secondary to the negative reflection effect upon which this formula is based. This might be expected in view of the fact that both diffraction and refraction tend to mitigate the additional attenuation that would be caused by reflection from a plane tangent to the earth's surface at the point of geometric reflection.

When the propagation is through built-up areas instead of over level terrain, the condition is more complicated. Even here, however, for terminals well above the tops of buildings, theoretical considerations[1] indicate that the same explanation of direct and reflected waves is valid. Data presented by Jones[4] may be used as a verification for this explanation even for transmission over buildings. Figure 11 of his paper shows that for heights between 170 and 1,500 feet the field is proportional to the height in accordance with equation 5. When the terminals are lowered within the building region, the field should decrease more rapidly than proportionally with the height above the ground. In fact, data presented in figure 4 indicate that, with one

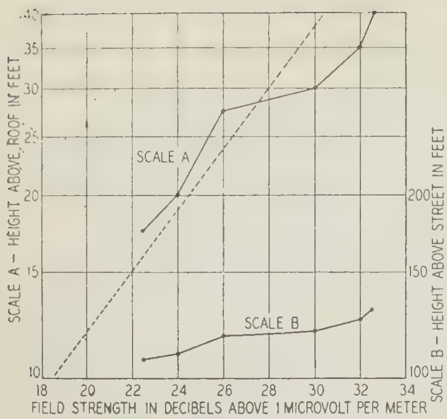


Fig. 4. Variation of field received at Berkeley and Stuart streets with antenna height

Curve A shows the variation with height above the roof, while Curve B shows the variation with height above the ground. The slope of the broken line indicates a linear relationship between field and height

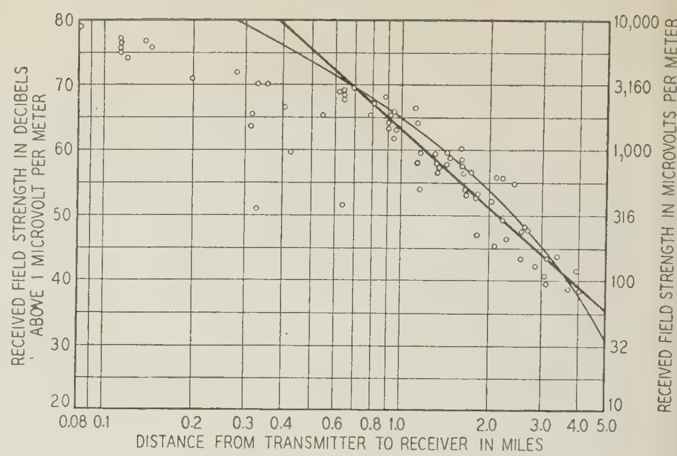


Fig. 5. Attenuation curve for 5 meter transmissions as replotted from paper by Muyskens and Kraus (see reference 7)

The straight heavy line shows an inverse-square-of-distance variation in accordance with the physical picture. The thin curved line is a replot of the curve presented by Muyskens and Kraus as representing these data by a variation according to an inverse-distance times an exponential factor. It is evident that these data may be interpreted equally well on the basis of the physical picture (heavy curve) as on the basis of the empirical equation assumed by Muyskens and Kraus

terminal above a flat roof that was of approximately the same height as other nearby flat roofed buildings, the field is more nearly proportional to the height above the roof than the height above the ground. When the terminals are lowered below the average building height, additional complications are introduced. While this is somewhat difficult to picture because of the irregularity of the surface bounding the transmitting medium (this surface is, of course, that formed by the ground and the walls and tops of buildings), the main outline seems simple enough. Above the building level there is a tendency for the field to follow the simple rules that hold for transmission over level country. In general, the field strength actually received in the street would be proportional to the field overhead, but of smaller amplitude since it is a product of scattering. This does not imply that the street signal comes down vertically; it probably is the result of scattering from points lying in a fairly large zone about the receiver and consists of a multiplicity of signals traveling in inclined directions.

Returning now to the present data on the propagation of ultra-short waves through urban areas, figure 2 shows that the field strength is in general inversely proportional to the square of the distance from the transmitter. (It will be shown later that the empirical formula assumed by Schröter, Sohnemann, Jones, and Muyskens and Kraus cannot be made to fit these data.) The mean curve through the data is 12 decibels below the curve for level terrain free from obstacles, plotted from equation 5, indicating the additional attenuation due to man-made structures. An analysis of the individual points shows that the reduction in field due to the obstacles (i. e., in addition to the level terrain attenuation) is independent of the distance so that there is no *absorption* due to the buildings in the usual meaning of the word; otherwise the additional attenuation would increase with the distance.

This method of interpretation is radically different from that of investigators of the propagation of ultra-short waves through urban areas whose papers have come to the attention of the authors[5, 6, 7]. They have assumed that the transmission occurs as in free space except for an additional attenuation *through the absorbing layer of buildings*. Such an assumption that the propagation of ultra-short waves is unaffected by the presence of the ground except in so far as the waves penetrate the absorbing layer of buildings, appears to be inconsistent with the physical picture[1,3,8,9] of ultra-short wave propagation which has been confirmed by basic experimental data.

The data presented by Muyskens and Kraus as figure 2 of reference 7 has been replotted in figure 5 of the present paper on logarithmic coördinates in order to facilitate reinterpretation on the basis of this physical picture. Figure 5 shows that it is possible to interpret their data as following an inverse-square-of-distance law equally as well as an inverse-distance law times an exponential factor. In this interpretation little weight has been given to the points that are well below the curve, in accordance with the view of the experimenters that these points represent particularly unfavorable receiving locations.

Trevor and Carter[8] have made a similar interpretation of the data presented by Jones[4] which shows that for the larger distances the field strength was inversely proportional to the square of the distance. If this inverse-square-of-distance curve were extended to shorter distances, it would be found that most of the nearby points would lie somewhat below it. This is presumably because of the lack of favorable receiving locations in the high building area. While the empirical formula arrived at by Jones may represent his data satisfactorily, the physical picture assumed of a free space field times an absorption factor is untenable since it requires a radiated power approximately 20 decibels below that measured. Undoubtedly the power radiated is not in error by this amount, since Trevor and Carter obtained a satisfactory numerical check on the basis of the other picture by using the value of power radiated as given by Jones.

It is possible, of course, to represent any data by

an inverse-distance factor times an exponential factor for a limited range of distances. An attempt to do this with the data of figure 2 by making the empirical curve agree with the experimental inverse-square-of-distance curve at 1 and 4 miles results in a curve that agrees well with the data between 0.6 and 5.0 miles but is 11 and 22 decibels low at 0.2 and 12.0 miles, respectively. Even if this discrepancy at the limits of the curve were neglected it would still be impossible to interpret the data in terms of the free space field times an exponential absorption factor, because the empirical curve so determined requires a radiated power 35 decibels below that measured; this is beyond reason since the over-all uncertainty in the absolute value of the measurements is only a few decibels.

It should be pointed out that each point of figure 2 represents the average field over an interval of either $^1/_{10}$ or $^1/_2$ mile depending upon whether the transmission path involved was less or greater than 2 miles. Within each interval the field varied by 5 to 15 decibels because of the local wave interference pattern, as is shown by the samples of the graphs taken with the recorder, which are presented in figures 6 and 7. Figure 6 is an example of the record taken in the business district of Boston at a distance of about $1^1/_2$ miles from the transmitter near the region *A* shown in figure 8. The maxima and minima are spaced very closely and differ by 10 to 15 decibels. This was characteristic of the type of record obtained at the shorter distances. At the greater distances the magnitude of the local variations was less, as illustrated by figure 7, which is a sample of the record taken at a distance of 5 miles (near *B* in figure 8). The change in the magnitude of the variations might have resulted from the fact that all the data for the greater distances were taken in residential districts with correspondingly lower heights and densities of buildings.

An idea of the variations to be expected from the inverse-square-of-distance relationship is shown by the contour map of figure 8. The data already presented will give an idea of the impossibility of showing much detail in such a map. Likewise it would be an almost endless job to make measurements on every street in a city of this size. While data were obtained within reasonable intervals over the area for which solid contours are drawn (continuous field strength records taken over 143 miles of street are represented by this figure), another set of data might result in a somewhat different looking map. The broken contours are not based upon field strength measurements, but are merely a plausible way of joining the solid contours to aid the eye of the reader. The 2 20 decibel contours in the lower part of the figure have not been joined because of insufficient data. The low field strengths along the Neponset River may be a result of local conditions, and possibly the 20 decibel contours should be continued to the right along an arc of more nearly constant radius. In this connection it may be mentioned that the field is nearly constant within the bulge of this contour to the southwest.

A striking fact brought out by the map is the crowding of the contours in the business district. There are particular directions for which the attenuation is greater presumably due to the combined effects of high buildings, for example to the east-northeast. There are other directions where the field strength is higher than the average. Several such places were noted when salt water extended immediately in front of the measurement location in the direction of the transmitter. The closed contours in the Mystic River to the north illustrate the better reception over salt water as predicted by theory.[1] An example of the records taken over bridges upon which these contours are based is shown in figure 9. (The route over which these data were taken is indicated at *C* of figure 8.) The average increase in field when going over bridges was 10 decibels. This may be explained by the better conductivity of the water, which results in a receiving directive characteristic that is more favorable to low angle reception. In some cases, the absence of buildings and increase in the height of the antenna due to the elevation of the bridge undoubtedly contributed to the greater field.

Another fact illustrated by the map is that the effects of obstacles and type of terrain are in general local. For example, the higher field strengths beyond salt water are soon reduced to normal with the intravention of additional land, illustrated at *D* in figure 8.

It was found that the field strengths along Columbus Avenue (indicated by *E* on figure 8) were about 10 decibels higher than those obtained on either side. This increase probably resulted from the fact that a more or less unobstructed optical path existed along Columbus Avenue.

While a detailed analysis of the attenuation of ultra-short waves over paths as complicated as those considered in this paper is impossible, the

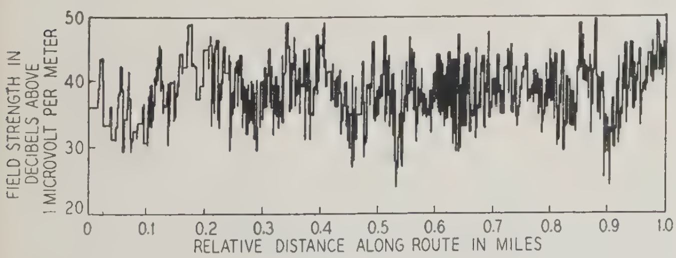


Fig. 6. Portion of record showing the large field strength variations as recorded while driving through the business district of Boston at a distance of about 1.5 miles from the transmitter

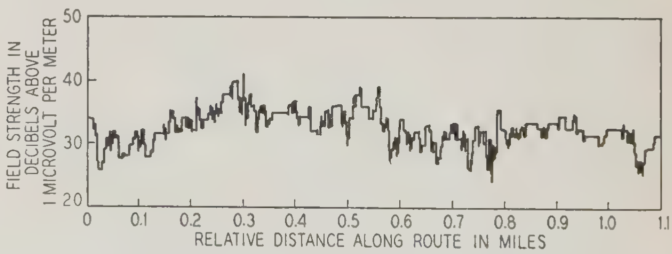
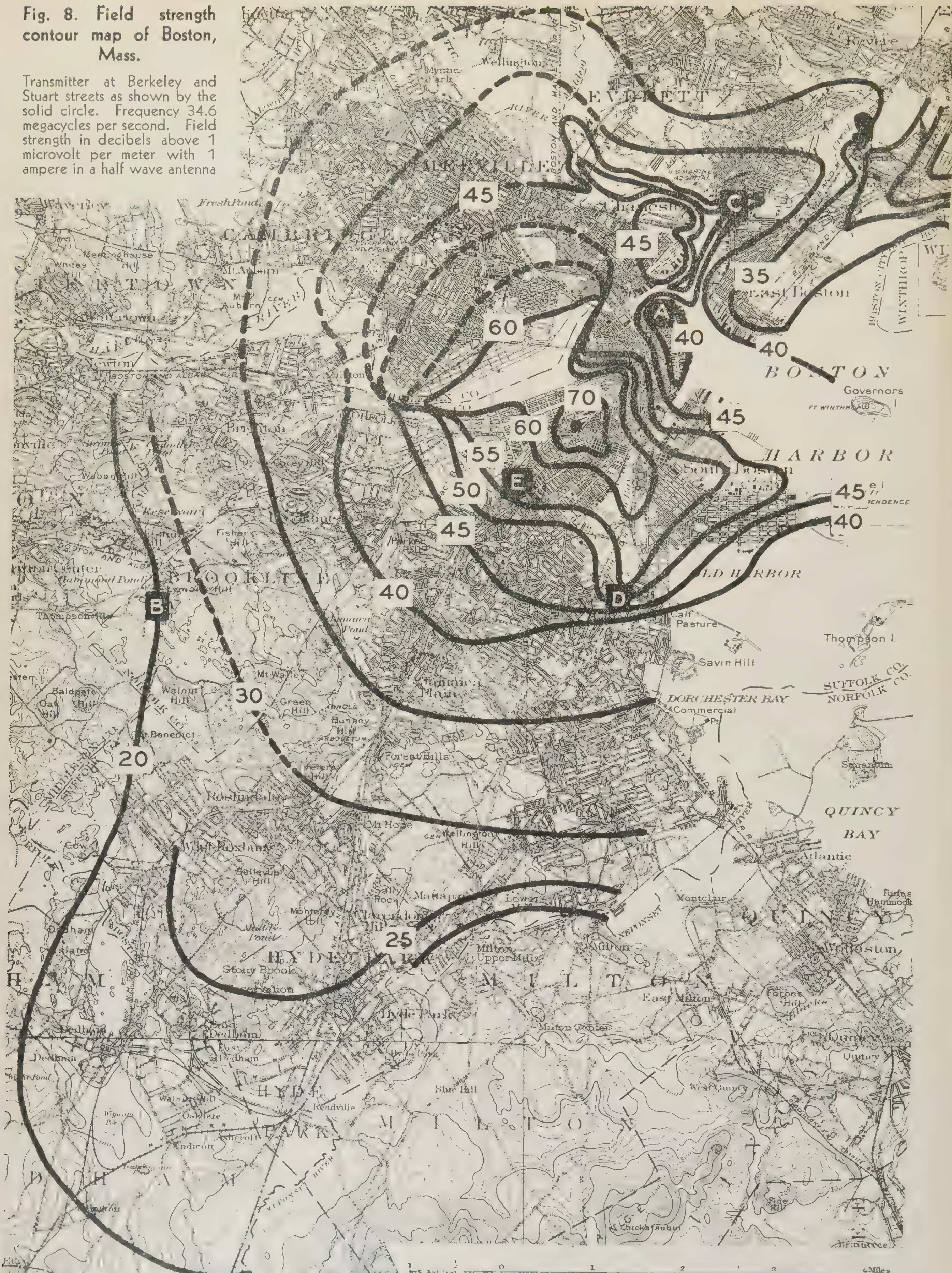


Fig. 7. Portion of record showing the small variations of field strength while driving through the residential section of Boston at a distance of about 5 miles from the transmitter

Fig. 8. Field strength contour map of Boston, Mass.

Transmitter at Berkeley and Stuart streets as shown by the solid circle. Frequency 34.6 megacycles per second. Field strength in decibels above 1 microvolt per meter with 1 ampere in a half wave antenna



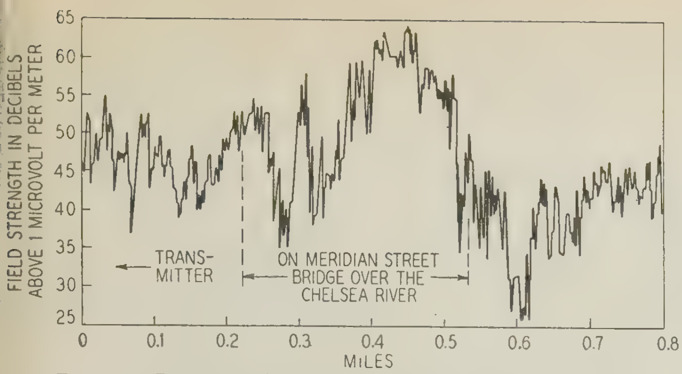


Fig. 9. Portion of records showing the variation of field strength on going over water

known facts indicate several general characteristics that seem worthy of mention for further experimental investigation. The fact that the field was found to be approximately proportional to the height of the antenna above the roof level of the surrounding buildings (figure 4) rather than to the height above the ground, as in the case of transmission over level terrain free from buildings, confirms the expectation that the "ground" conditions in the immediate vicinity of the fixed terminal would play an important part in determining the magnitude of the received field strength.

It is perhaps correct to assume that for the fixed terminal the height to be substituted in equation 5 should be the height above the roof rather than the height above ground. This would reduce the level terrain curve of figure 2 by 10 decibels.

Figures 6, 7, and 9 show marked wave interference patterns which indicate reflections from a multiplicity of points in the immediate vicinity of the mobile terminal. Besides these variations in the magnitudes of the fields observed at points in close proximity to each other, which are undoubtedly caused by reflections from irregularities in the immediate vicinity of the terminal, there are the variations represented by the spread of the points about the mean curve (figure 2). That these variations may be attributable to conditions local to the terminal is indicated by the fact that the increase in field on the far side of salt water and the decrease in the field on the far side of hills, etc., do not persist at further distances. Even if the irregularities of the contours of figure 8 were removed, the contours would not be concentric circles about the transmitter. At this stage in the development it would be unwise to attempt to say how much of the deviation of the contours from circles may be attributable to directional characteristics at the fixed terminal and how much to the intervening terrain. Statistically speaking, however, it is safe to say that the additional attenuation attributable to deviations from level terrain such as is produced by the presence of buildings, is independent of the length of the transmission path, so that there is no *absorption* in the usual meaning of the word. Another experimental result that points to the possibility that the effect of the buildings is local may be deduced from the data presented by Jones[4] and by Trevor and Carter.[8] The latter showed that the more distant points lie on the inverse-square-of-distance curve expected for transmission over level terrain free from buildings. The nearby points, however, lie below this curve, indicating that the major effect of the buildings is a local one.

The greatest difficulty encountered in attempting to apply the results of these experiments to the predetermination of the field to be expected for transmission in other cities would be the interpretation of the method of assigning values to the heights in equation 5. While sufficient data are not available to establish an empirical relation, for a first estimation it seems reasonable that if the height of the fixed antenna were measured from the average roof level of the surrounding buildings and the height of the mobile antenna were measured from the street level, the resulting field strengths would lie within the range of expected values.

Field Strength Measurements: Receiver at a Fixed Location

The field strength data obtained with the receiver at Seaverns Street and the transmitter in the truck are shown in figure 10. These data may be represented also by an inverse-square curve. By comparison with figure 2 no differences that can be attributed to the change in position of the fixed terminal nor the direction of transmission is evident. There is a small difference in the separation between the mean curves and the level terrain curves, but in both instances the mean curve lies very close to the level terrain curve (not shown) that would result from measuring the antenna height of the fixed terminal from the average roof level instead of from the ground.

Most of the nearby points were taken in the park system. They indicate that it is not more difficult

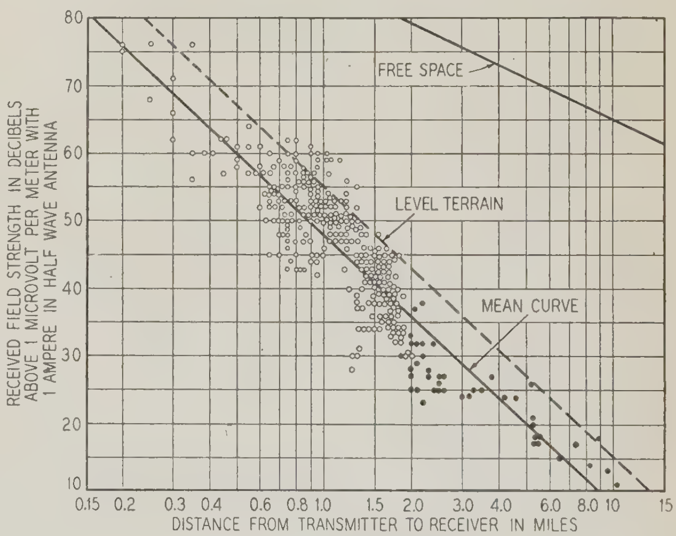


Fig. 10. Mass plot of field intensities measured with the transmitter at various distances about the Seaverns Street location

The open circles represent fields averaged over 1/10 mile intervals while the solid circles represent averages over 1/2 mile intervals

Fig. 11. Field strength contour map of Boston, Mass.

Receiver on Seaverns Street near Center Street as shown by the solid circle. Frequency 34.6 megacycles per second. Field strength in decibels above 1 microvolt per meter

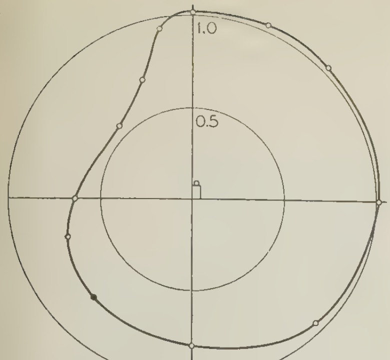


Fig. 12. Directional characteristic in the horizontal plane of the mobile receiver

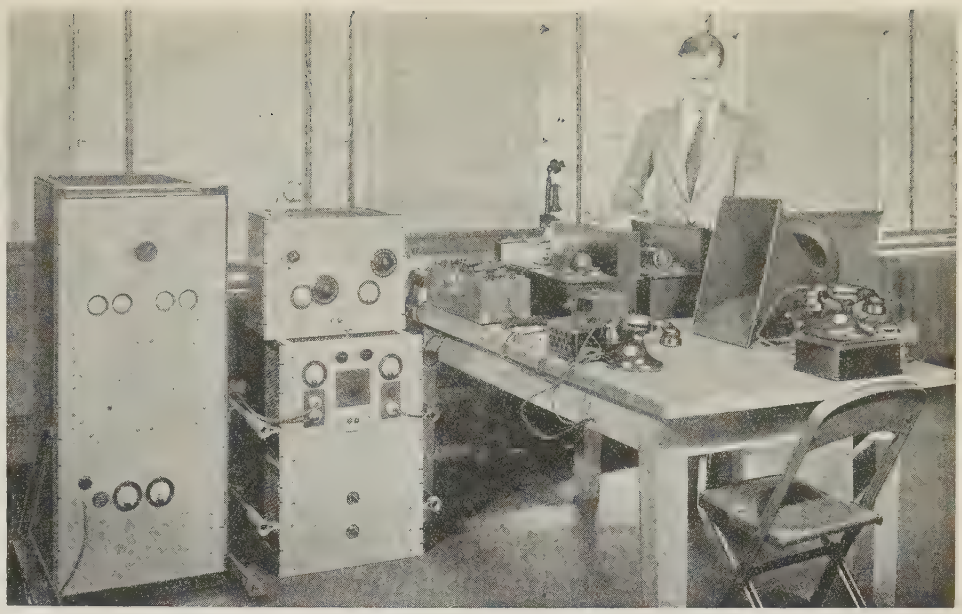


Fig. 13 (right). Fixed terminal transmitting equipment at Berkeley Street

to transmit through wooded areas than through built-up sections.

A field strength contour map illustrating the results with the receiver fixed at Seaverns Street is shown in figure 11. The disturbing effect of hills is illustrated at several points on the map. There was a reduction of field strength when the transmitter was behind either Bussey Hill at A on the map or Green Hill at B, while the field was higher when the transmitter was between them. There was a rather deep minimum when the transmitter was immediately behind Parker Hill at C to the north, but $^1/_2$ mile further away there was no noticeable effect.

Effect of Obstacles

In the course of the measurements some qualitative observations were made which will be summarized in this section. It was noticed in particular that when the receiver passed underneath an intersection of overhead trolley wires, the field was somewhat reduced. An example of this effect was observed at the intersection of Massachusetts and Huntington avenues where the reduction was 15 decibels. At this point the maze of overhead trolley and support wires apparently constituted a fairly efficient screen for these waves. Observations made during the tests showed that sometimes the field was reduced considerably on the far side of hills as has been brought out by the contour maps. A large reduction in field strength resulted upon going behind a low hill on Saratoga Street in Breeds Island. The most striking example of this effect occurred with the measuring set at Seaverns Street and the mobile transmitter being driven from Huntington Avenue onto South Huntington Avenue (C of figure 11). Soon after rounding the corner at the foot of Parker Hill, which is 200 feet high, the average field dropped about 15 decibels.

The field was 20 decibels lower under Funeral Bridge than on either side of it. This is a stone and earth bridge appearing as a short tunnel to the road beneath it. The field usually was reduced upon passing underneath bridges of this general type of construction.

A separation of the field strengths into those obtaining in the high-building area (indicated by open circles in figure 2) from those in the lower-building area (indicated by solid dots) shows that the attenuation is somewhat greater in the former.

No effect of the elevated railway structures on the average field was observed.

Noise Measurements

For reception in the car, by far the greatest interference is that caused by the electrical systems of passing automobiles. Special tests to determine whether or not street cars produced any noise gave a negative result; that is, under conditions where automobile noise was a limitation to reception, trolley noise was inaudible. While no special tests were made of the noise from elevated trains, at no time was it found objectionable.

With the receiver on top of the building at Berkeley and Stuart streets, the predominating interfering noise was caused by an electrical substation next door. When the antenna was lowered approximately to the roof level the noise from the elevator motors and switching equipment in the penthouse nearby was well above any other noise. Upon raising the antenna to its proper position the elevator noise was reduced to a negligible amount compared with the power station noise, because of the combined effect of the directivity of the antenna and increased distance. The resulting noise was of approximately the same magnitude, indicating that the elevator switching noise was reduced by a fairly large factor in raising the antenna. This fact has an important bearing on reception of signals on the roofs of office buildings, since elevator switching noise is in general the limiting factor. Occasionally an automobile, started in the street below, would produce measurable interference. At Seaverns Street, however, the most

objectionable noise was caused by the ignition systems of automobiles that were accelerating in low gear in the street below.

The authors wish to acknowledge the coöperation of the New England Telephone and Telegraph Company and the Graybar Electric Company, and also Commissioner E. A. Hultman and Signal Director T. A. J. Hayes, both of the Boston police department.

Appendix

Methods of Calibrating

In order to obtain an absolute calibration of the measuring equipment, the field strengths at a distant point in space at the same height above the ground as the center of the receiving antenna was obtained by a standard method of field strength measurement. This method consists of comparing the unknown field with a known field produced by a "standard field generator," which is a small compact self-contained oscillator. It is very carefully shielded except for a small balanced loop extending in a vertical plane above the shield. A thermomilliammeter is located in the loop at the point of low potential with respect to the shield. From the reading of the meter and the dimensions of the loop, the field at nearby points may be computed. (See *Proceedings* of the Institute of Radio Engineers, volume 21, March 1933, pages 430–1.) This equipment then was removed and the truck placed in such a way that its antenna was always at the point where the field strength had been determined. By pivoting the truck about the point, the horizontal polar diagram of the mobile receiving equipment was obtained. It is shown in figure 12. As the field was known at this point in the absence of the truck, the attenuator settings gave a calibration of the receiving equipment for all directions. With this calibration as a standard, an auxiliary standard field generator which employed a loop radiator attached to the opposite side of the truck was calibrated also. The auxiliary generator then was used throughout the test to check the calibration of the receiver. Since the polar diagram was fairly constant on the right side of the truck, care always was taken to orient the truck in such a way that the direction of the transmitter was at the right side rather than the left.

When the receiver was at Berkeley and Stuart streets it was possible to employ the usual method of calibration as described in the preceding paragraph, because the roof was flat. With the receiver at the Seaverns Street location, however, the gabled roof made it impractical to support the standard field generator opposite the midpoint of the antenna. In the latter case, accordingly, the constancy of the gain of the receiving equipment was depended upon in reducing the measurements to field strengths in absolute units. This lack of calibration did not introduce a large uncertainty, since the receiving equipment has been used over a period of years during which time its gain has remained constant within a few decibels.

Two-Way Tests

At the conclusion of this survey, actual 2-way tests were made between a cruising car and fixed locations. For this purpose a car was equipped by E. B. Ferrell and R. C. Shaw (both of Bell Telephone Laboratories, Deal, N. J.) with an ultra-short wave transmitter and receiver arranged for simultaneous 2-way communication. A distinctive feature of this equipment was the use of a single antenna for simultaneously transmitting and receiving. This was made possible by the use of a suppressor circuit in the receiver to prevent overloading of the first detector by the outgoing signal. With this suppressor circuit, which consisted of only a half section of a simple band-elimination filter, it was possible to transmit and receive simultaneously on frequencies differing by only 5 per cent. The equipment at the fixed transmitting location is shown in figure 13.

The car was used for communication at distances up to about 5 miles from the fixed transmitter and up to a little more than 3 miles from the fixed receiver. The circuit from the moving car to the fixed receiver was consistently good for distances up to about 2 miles.

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Modern Transportation—An All-Metal Passenger Plane

ONE of the new all-metal Douglas airliners which are in service on the lines of Transcontinental and Western Air, Inc., flying low over city buildings. Airliners of this same type will be at Newark, N. J., airport during the Institute's forthcoming winter convention at New York, January 22–25, 1935. Inspection trips scheduled include visits to the plant of the Wright Aeronautical Corporation, at which the manufacture of the engines used in the Douglas airliner may be seen, and to Newark airport, where these planes will be available for those who wish to schedule flights over the city in them. Some details of this plane were given in Electrical Engineering for February 1934, page 349.

News

Of Institute and Related Activities

Winter Convention Program Offers Many Attractive Features

A SCHEDULE of events replete with both professional and social activities has been arranged for the A.I.E.E. winter convention to be held in the Engineering Societies Building, 33 West 39th Street, New York, N. Y., January 22–25, 1935. The convention will open on a Tuesday and technical sessions will be held during the mornings and afternoons of the first 3 days. In the evenings a smoker which this year will be a radical departure from the time-honored type, medal presentations and demonstration lecture, and the dinner-dance will be held. In addition special entertainment has been arranged for the visiting ladies. Friday, the last day of the convention, will be devoted entirely to inspection trips to a number of places of interest in New York and vicinity, some of which are entirely new and have not been seen heretofore. The program will be interspersed with important committee meetings and those who attend will have a busy and profitable week with ample opportunity for social enjoyment.

Schedule of Events

A summarized schedule of events follows. Capital letters A, B, etc., denote technical sessions.

Tuesday, January 22

9:00 a.m.	Registration
10:00 a.m.	Opening of convention
10:30 a.m.	A—Electrical machinery
	B—Communication
2:00 p.m.	C—Transformer symposium
	D—Education
6:00 p.m.	Smoker at Casino de Paree

Wednesday, January 23

10:00 a.m.	E—General overhead line problems
	F—Noise symposium
2:00 p.m.	G—Illumination
	H—Electric welding
8:15 p.m.	John Fritz Medal presentation
	Edison Medal presentation
	Demonstration lecture

Thursday, January 24

10:00 a.m.	I—Electronics symposium—I
	J—Cables
2:00 p.m.	K—Electronics symposium—II
	L—Induction motor symposium
7:00 p.m.	Dinner-dance at Hotel Pierre

Friday, January 25

All day.	Inspection trips

Technical Session

The technical program was planned to present to the membership the latest advances in the theory and practice of electrical engineering and the allied arts. Among the 53 papers to be presented in 12 technical sessions much subject matter will be found that is of interest to the average engineer as well as the specialist. The program as announced in Electrical Engineering for December 1934, pages 1662–3, is complete with the addition to the session on communication of the paper entitled "Ultra-Short Wave Propagation" by C. R. Burrows, L. E. Hunt, and Alfred Decino, all of the Bell Telephone Laboratories, Inc. All of the papers have been published in advance of the convention, the issue of Electrical Engineering in which each paper appears having been given in the above-mentioned program.

In addition to the 12 technical sessions several informal sessions with round-table discussions on the subjects of transformers, the induction motor test code, and sound will be held. The papers and discussions given at these informal meetings will not be published but engineers are invited to attend these meetings and feel free to take part in the discussions. Notice of the meeting room locations will be posted on the bulletin board during the convention.

Following are special comments on one of the symposiums, that on noise.

Noise Symposium

Important progress has been made during recent months by the committees of the American Standards Association working on the problems of noise measurement and standards, so that the forthcoming noise symposium to be held on Wednesday, January 23, is being looked forward to with great interest. At the meeting of the Acoustical Society in Pittsburgh during the last week in December several papers dealing with the general question of noise measurement were presented and a discussion was participated in by a number of engineers and physicists present. A feature of the meeting was a paper presented by B. G. Churcher, of the Metropolitan-Vickers Research Laboratory, which brought to the meeting at first hand the experiences of one of the leaders in this field in England. Mr. Churcher will also present a paper at the Institute convention, dealing in this case more specifically with the practical problems of noise measurement in the field.

The symposium will be opened by a statement by R. G. McCurdy, chairman of the A.S.A. technical committee on noise meters and noise levels. He will outline the technical points on which agreement is required to secure identical readings when the same noise is measured with different meters, and will explain the conclusions so far reached by the committee. The work of this committee is based upon the fundamental standards of noise measurement agreed upon by Dr. Harvey Fletcher's subcommittee of the A.S.A. on noise measurement, and which are now being given final consideration by letter ballot.

With the completion of these standards the various industries will be in a position to experiment with the new noise meters to ascertain the most satisfactory practical means for measuring noise produced by their own types of equipment so as to arrive at acceptable standard test conditions for each type of apparatus and thus be able to determine if any given piece of equipment meets noise specifications. In order to facilitate coördination among the various industries and technical bodies engaged in this problem, the committee on standardizing the noise meter has been enlarged in its personnel and scope and designated a technical committee on noise meters and noise levels. It is contemplated that it shall act as an advisory group to industry on this subject and as a clearing house for the exchange of information. All of this activity by providing language in which noise specifications may be expressed and adequate technical methods for determining if these requirements are met should place the various industries in a far better position than ever before to serve the public demand for quieter apparatus and to secure recognition for results which may be accomplished.

Following Mr. McCurdy's statement on the status of the standardization work, Mr. Churcher will present a paper on his experiences in England on the measurement of noise under a variety of conditions. Three other papers will be presented by A. P. Fugill, C. G. Veinott, and E. J. Abbott, dealing with field experiences in noise measurement, noises from transformers and fractional horsepower motors, and specific methods for quieting of substations. The entire program should appeal to all those interested in the problem of reduction of noise from electrical machinery and apparatus as well as those engaged in the rapidly developing art of noise measurement.

Medal Presentations and Demonstration Lecture

The Edison Medal will be presented to Dr. Willis R. Whitney in the engineering auditorium on the evening of January 23 at 8:15 p.m. The medal has been awarded to Doctor Whitney "for his contributions to electrical science, his pioneer inventions, and his inspiring leadership in research." A personal sketch of Doctor Whitney's career is given in a "personal" item on page 139 of this issue.

The John Fritz Medal awarded to the late Dr. Frank Julian Sprague for "distinguished service as inventor and engineer through

the application and control of electric power in transportation systems" will be presented to a member of his immediate family. Details regarding this award were published in ELECTRICAL ENGINEERING for December 1934, page 1664.

At the conclusion of the medal presentation ceremonies, a demonstration lecture on "New Developments in Illuminants and Their Application" will be given by A. L. Powell, president of the Illuminating Engineering Society.

In view of the limited seating capacity of the auditorium admission to the medal presentations and the lecture will be by ticket only.

SMOKER

As in the past the smoker again will be held on the first evening of the convention, that is, Tuesday, January 22, 1935. However, in order to eliminate the inconveniences that were unavoidable in holding the affair at the Engineering Societies' Building, the committee has decided on a radical but promising innovation. Arrangements have been made with the management of the Casino de Paree, 254 West 54th St., New York, N. Y. The Casino will be reserved for A.I.E.E. members and their friends from 6:00 p.m. to 10:30 p.m. An unusually fine course dinner will be served followed by the regular show. In your interests the committee has sampled the dinner and the show; both received unanimous approval. There will be lots to eat and you will eat in comfort with ample room to move around and meet your friends. Then without leaving your table you get an unobstructed view of a fine show. Finally the price this year has been reduced to $2.35 per person, including tax. Enter your order for tickets early with H. E. Farrer, A.I.E.E. Headquarters, 33 West 39th St., New York, N. Y., as the committee expects to more than fill the house.

ANNUAL DINNER-DANCE AND BUFFET SUPPER

The outstanding social event of the winter convention will be held Thursday, January 24, 1935, at the Hotel Pierre, Fifth Avenue and 61st St., New York. It is to be a combination dinner-dance and dance-buffet supper.

The program offers for your selection several combinations designed to retain all the pleasurable features of long standing and the innovations of last year's successful affair, in surroundings that are unexcelled.

Music will be furnished by George Ellner's orchester whose fascinating rhythm and emotional harmonies ensure perfect enjoyment. They will play a sufficient number of dances to enable you to inflict yourself upon all of your friends. The entire ballroom floor of the Hotel Pierre, one of New York's newest and smartest hotels, will be available for your enjoyment. The spacious Grand Ballroom for dinner and dancing, the Corinthian Room for supper, and the several lounge rooms for beverage service and for bridge and other games are all beautiful. Most delectable menus have been prepared for the dinner and supper, with a wide choice to be had for the latter. Transportation by subway is convenient and parking facilities in the neighborhood are good or, if desired, will be provided by the Hotel Pierre for a moderate fee.

The program is as follows:

7:00 p.m.	Annual dinner	Grand Ballroom
9:30 p.m. to 2:00 a.m.	Dancing	Grand Ballroom
Midnight to 2:30 a.m.	Buffet supper	Corinthian Room

The cost of tickets per person will be as follows:

Dinner—dance—buffet supper	$6.50
Dinner—dance	5.00
Dance—buffet supper	3.00

Tables will be laid for 8 or 10 places. Send reservation requests promptly to the A.I.E.E. dinner-dance committee, 33 West 39th Street, New York, N. Y., and make checks payable to H. H. Henline, national secretary. Please indicate names of guests and desired seating arrangement. Every effort will be made to comply with the requests. To assist the committee in making arrangements, please purchase tickets early.

Radio Room at New York City Police Headquarters

VISITORS to the Institute's 1935 winter convention will have the opportunity of inspecting the police radio equipment installed for New York City. The dispatcher's control map in the radio room at police headquarters is shown here. The numbered brass disks on the map indicate the location of radio patrol cars.

Future AIEE Meetings

Winter Convention,
New York, N. Y., Jan. 22–25, 1935

South West District Meeting,
Oklahoma City, Okla., Apr. 24–26, 1935

Summer Convention,
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention,
Los Angeles vicinity, Fall 1935

Great Lakes District Meeting,
Indianapolis—Lafayette Section territory (date to be determined)

WOMEN'S ENTERTAINMENT

In addition to the social events on the program the women's entertainment committee, Mrs. H. R. Woodrow, chairman, has arranged special entertainment for the visiting women. A luncheon and bridge will be given, a visit will be made to the Good Housekeeping Institute, and the Damrosch broadcast will be attended, together with a tour of the studio.

INSPECTION TRIPS

The inspection trips committee has arranged a program embracing a wide variety of subjects, many of them to be seen for the first time by Institute members. Power, transportation, communication, and illumination will be covered by inspections of significant developments in each of these fields. In addition, several trips to points of general engineering interest are planned. In spite of the times there are many new things to be seen in and about New York.

Last year's plan of reserving all day Friday for inspection trips will be repeated, but opportunity will be offered during the other days of the convention to visit points of interest, some of them chosen because of

Membership—

Mr. Institute Member:

This month the membership committee is inviting into Associate membership those Students who were graduated last June. There are 1,244 of these young men. Personal letters from Institute headquarters and personal contacts from the Section membership committees bring the invitation.

The membership committee asks that where you may know any of these young men you acquaint them further of Institute activities.

Chairman National Membership Committee

their relationship to specific subjects on the technical program.

The following tentative schedule is proposed:

Tuesday, January 22

1. Long lines department—American Telephone and Telegraph Company
2. Radio communication facilities—New York police department. (Also on Friday)

Wednesday, January 23

1. Midtown vehicular tunnel
2. Seatrane Lines, Inc.
3. Warner Bros. moving picture studio
4. Hudson Avenue generating station—Brooklyn Edison Co., Inc.
5. Sodium vapor street lighting installation on Jerome Avenue, Bronx

Thursday, January 24

1. New light weight subway train
2. "Million dollar street car"
3. Electrical Research Products, Inc.
4. Mercury turbine and Kearny generating station—Public Service Electric and Gas Company

Friday, January 25

1. Edgewater plant—Ford Motor Company
2. Okonite-Callender Cable Company
3. Wright Aeronautical Corporation
4. Radio City Music Hall
5. General Electric "House of Magic"
6. Radio communication facilities—New York police department. (Also on Tuesday)
7. Airplane flights from Newark airport
8. S. S. California—Panama Pacific Line
9. R.C.A. Radiotron Company

One of the most interesting items on the program is an all-day trip by motor bus leaving headquarters at 9:30 a.m., Friday, January 25. An inspection of the Edgewater plant of the Ford Motor Company in the morning will be followed by luncheon for the party as guests of that company. In the afternoon the trip will continue to Paterson, N. J., where visits to the plants of the Okonite-Callender Cable Company and the Wright Aeronautical Corporation will be made. The return route will include the George Washington Bridge.

Another Friday trip which should prove popular is a visit to Newark airport where an opportunity to fly in one of the new Douglas air liners will be had.

On Wednesday afternoon, January 23, a bus trip will be made to the Warner Bros. studios where the actual "shooting" of movies may be seen as well as the sound equipment and incandescent lighting. On return a stop will be made at the Hudson Avenue station of the Brooklyn Edison Company, Inc., where competent guides will conduct the party and explain many of the interesting features of this large station.

Because of possible changes in the above schedule brought about by unforeseen developments, inquiry should be made at the inspection trips desk at the opening of the convention. It is requested that members make reservations for the regular trips and arrangements for special trips promptly. In certain cases a nominal charge for transportation will be made.

In addition to the regularly scheduled trips, visits may be arranged through the inspection trips committee to a large number of points of restricted or special interest, a list of which will be available.

Register in Advance

Fill in and post promptly the mail registration card which was included with the mailed announcement of the winter convention sent to members in nearby Districts. This will permit the committee to have badges ready and prevent congestion at the registration desk upon arrival. There will be a registration fee of $2 for nonmembers with the exception of Enrolled Students of the Institute, and the immediate families of members.

Hotel Accommodations

One of the hotels within a 15 minute walk from convention headquarters is offering to A.I.E.E. members attending the convention a special "all expense" rate of $11.20 covering all essential services for the period of the convention exclusive of lunches and also exclusive of dinners on the evenings of which the Institute has dinner functions. For details write at once to National Secretary Henline for descriptive booklet and full information. In all other cases, hotel reservations should be made directly with the hotels.

Reduced Railroad Rates

Fare and one-third for the round trip over the same route will be available to members and guests, provided 100 certificates are validated at the registration desk. Consult your local ticket agent regarding the territory and dates applicable. Obtain your certificate authorized by the railroad passenger associations.

Announcement of Special Dinners

A dinner for Columbia electrical engineers will be held on Wednesday, January 23, 6:30 p.m. at the Columbia University Club, 4 West 43rd Street. The dinner will conclude in time to permit attendance at the Edison Medal presentation. Price for the dinner is $1.50. Apply for reservations to J. W. Balet, 4 Irving Place, New York, N. Y.

The Union College Engineers' Club has an annual dinner each year in New York. The next dinner takes place on January 25 at 6:30 p.m. at the Phi Gamma Delta Club, 106 West 56th Street, New York City.

A.I.E.E. Executive Committee Meets

A meeting of the executive committee of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on December 7, 1934.

Present: J. Allen Johnson, chairman; H. P. Charlesworth, F. M. Farmer, Everett S. Lee, W. I. Slichter, R. H. Tapscott, and J. B. Whitehead, members of the committee; L. W. W. Morrow, A. C. Stevens, and A. M. Wilson, other members of the board of directors; and H. H. Henline, national secretary.

A resolution was adopted in memory of Dr. Frank Julian Sprague, a past president of the Institute, who died on October 25, 1934. (The resolution appears on page 128 of this issue.)

A report of a meeting of the board of examiners held on November 27, 1934, was presented and approved. Upon the recommendation of the board of examiners, the following actions were taken: 1 applicant was transferred to the grade of Fellow; 38 applicants were elected and 47 were transferred to the grade of Member; 93 applicants were elected to the grade of Associate; 751 Students were enrolled.

The finance committee reported monthly disbursements amounting to $18,702.93.

Upon the recommendation of the committee on student Branches, the organization of a student Branch at Union College, Schenectady, N. Y., was authorized.

The national nominating committee reported its selection of an official ticket of nominees for election, in the spring of 1935, to Institute offices becoming vacant August 1, 1935. Information concerning the nominees appears on pages 128–9 and pages 137–9 of this issue.

Approval was given to a revision of the

by-laws of the United Engineering Trustees, Inc.

A communication from the American Society of Safety Engineers, Engineering Section, National Safety Council, regarding a plan for coöperation between agencies concerned with the technical aspects of accident prevention work, was referred to the committee on safety codes.

Other matters were discussed, reference to which will be found in this or future issues of ELECTRICAL ENGINEERING.

In Memoriam

THE death, on October 25, 1934, of Dr. Frank Julian Sprague removed from the American Institute of Electrical Engineers its eighth President, a member who had been active in its affairs for 47 years.

While a student at the U.S. Naval Academy, he became deeply interested in electrical and mechanical developments and the studies and experiments conducted during his free time for several years after his graduation, in 1878, led to many inventions. The inventive urge was so strong that he soon resigned from the Navy, and, after assisting Thomas A. Edison for one year, he organized, in 1884, the Sprague Electric Railway and Motor Company.

FRANK J. SPRAGUE

His technical and inventive ability, his success in managing the financial affairs of the companies which he organized, and his keen perception of future needs for electrical methods in the industries made his career one of outstanding success, and brought him fame for many particular achievements, especially those in the development of high speed elevators, electric traction, and remote control systems.

His work brought him many high honors, including medals and honorary degrees, and he was informed only a few days before his death that the John Fritz Medal for 1935 had been awarded to him.

Doctor Sprague joined the Institute in 1887, and was transferred to the grade of Member in 1897, and to the grade of Fellow in 1912. He was elected an Honorary Member in 1932. He served on various Institute committees, as vice president 1890–92, and as president 1892–93. The Institute awarded the Edison Medal to him in 1910.

RESOLVED: That the executive committee of the American Institute of Electrical Engineers hereby expresses, upon behalf of the membership, its deepest regret at the death of Doctor Sprague, and its sincere appreciation of his many important contributions to its activities and to the development of the entire engineering profession, and be it further

RESOLVED: That these resolutions be entered in the minutes and copies be transmitted to members of his family.

—A.I.E.E. Executive Committee, Dec. 7, 1934

"A Summer Convention for the Entire Institute"

Plans being made for the Institute's 51st annual summer convention, to be held at Ithaca, N. Y., June 24–28, 1935, indicate that particular emphasis is being placed on securing arrangements which will make the convention available to the largest possible number of members. It is planned to make it a convention that all members can afford to go to, enjoy, and profit by. All of the features included in previous summer conventions are expected to be included, as well as several innovations.

One feature is that there will be no registration fee. Another, the college dormitories will be open to members of the Institute at a very low rate during the convention week. Also, the food at the Cornell Cafeteria is reported to be exceptionally good and unusually low in price. On the other hand, plans are being made for the hotels to furnish the customary first-rate accommodations. The usual sports of golf and tennis will be featured, as well as other simpler forms of amusement.

In addition to the usual technical and other sessions, several informal group meetings are being planned at which topics of interest to special groups may be presented and discussed. It is hoped that all those interested in any such conferences on special topics will get in touch immediately with Prof. W. H. Timbie, Massachusetts Institute of Technology, Cambridge, Mass., so that arrangements for such conferences may be made.

Nominating Committee Announces Candidates

A complete official ticket of candidates for the Institute offices that will become vacant August 1, 1935, was selected by the national nominating committee at its meeting held at Institute headquarters, New York, December 7, 1934. This committee, in accordance with the constitution and by-laws, consists of 15 members, one selected by the executive committee of each of the 10 geographical Districts, and the remaining 5 selected by the board of directors from its own membership.

The following members of the committee were present: Walter Brenton, Portland, Ore.; H. P. Charlesworth, New York, N. Y.; A. B. Cooper, Toronto, Ont.; R. F. Danner, Oklahoma City, Okla.; L. F. Fuller, Berkeley, Calif.; W. B. Hall, New Haven, Conn.; F. H. Lane, Chicago, Ill.; Everett S. Lee, Schenectady, N. Y.; W. S. Rodman, Charlottesville, Va.; G. H. Sechrist, Laramie, Wyo., C. E. Stephens, New York, N. Y.; A. C. Stevens, Schenectady, N. Y.; J. B. Whitehead, Baltimore, Md.; and A. M. Wilson, Cincinnati, Ohio.

The following is a list of the official candidates selected by the committee:

FOR PRESIDENT

E. B. Meyer, vice president, United Engineers and Constructors, Inc., Newark, N. J.

FOR VICE PRESIDENTS

W. H. Harrison (Middle Eastern District, number 2), vice president, Bell Telephone Company of Pennsylvania, Philadelphia, Pa.

Mark Eldredge (Southern District, number 4), chief engineer, Memphis Power and Light Company, Memphis, Tenn.

R. H. Fair (North Central District, number 6), plant operations supervisor, Northwestern Bell Telephone Company, Omaha, Neb.

N. B. Hinson (Pacific District, number 8), chief engineer, Southern California Edison Company, Los Angeles, Calif.

C. V. Christie (Canada District, number 10), professor of electrical engineering and chairman, department of electrical engineering, McGill University, Montreal, Quebec.

FOR DIRECTORS

C. R. Jones, eastern transportation manager, Westinghouse Electric and Manufacturing Company, New York, N. Y.

W. B. Kouwenhoven, professor of electrical engineering and assistant dean, Johns Hopkins University, Baltimore, Md.

G. C. Shaad, dean, school of engineering and architecture, University of Kansas, Lawrence, Kans.

FOR NATIONAL TREASURER

W. I. Slichter, professor of electrical engineering, Columbia University, New York, N. Y.

The constitution and by-laws of the Institute provide that the nominations made by the national nominating committee shall be published in the January issue of ELECTRICAL ENGINEERING. Provision is made for independent nominations as indicated in the following excerpts from the constitution and by-laws:

CONSTITUTION

Sec. 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the by-laws; such petitions for the nomination of vice presidents shall be signed only by members within the District concerned.

BY-LAWS

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various

offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (Constitution), must be received by the secretary of the national nominating committee not later than February 15th of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with Article VI of the Constitution and sent by the national secretary to all qualified voters during the first week in March of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(*Signed*) National Nominating Committee
by H. H. Henline,
Secretary

Biographies of Nominees

That those not personally acquainted with the nominees may know something of them and their qualifications for the Institute offices for which they have been recommended, brief biographical sketches are given on pages 137–9 of this issue.

Great Lakes District Executive Committee Meets

A meeting of the executive committee of the A.I.E.E. Great Lakes District (number 5) was held in the rooms of the Electric Club, Civic Opera Building, Chicago, Ill., September 28, 1934.

Those that attended were G. G. Post, vice president, and chairman of the District executive committee; Burke Smith, secretary, Chicago Section; J. A. Rogers, vice chairman, Chicago Section; J. R. North, chairman, Detroit-Ann Arbor Section; O. Kiltie, chairman, Fort Wayne Section; D. H. Hanson, secretary, Fort Wayne Section; F. R. Finehout, secretary, Indianapolis-Lafayette Section; B. S. Willis, chairman, Iowa Section; R. E. Johnson, chairman, Madison Section; C. D. Brown, chairman, Milwaukee Section; J. H. Kuhlmann, secretary, Minnesota Section; L. L. Smith, chairman, Urbana Section; K. A. Auty, District treasurer; and A. G. Dewars, District secretary.

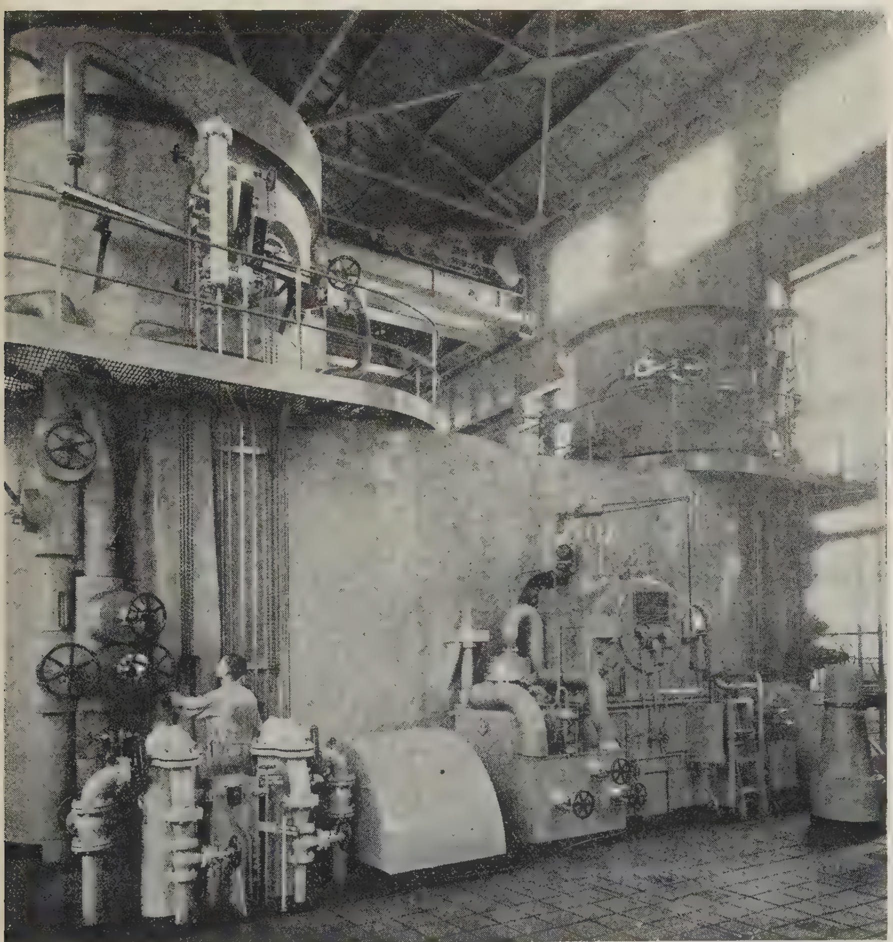
After approving the minutes of the 1933 meeting, the District treasurer's report was read. A cash balance of $306.63 in addition to a holding of stock having a market value of $774 was shown.

K. A. Auty was unanimously reëlected to succeed himself as District treasurer. F. H. Lane was unanimously elected to serve as the District representative on the national nominating committee. The following were unanimously elected to serve on the District coördinating committee which, with 2 members of the sponsoring section, will be in charge of the coming District meeting: T. F. Irvine, chairman, Indianapolis-Lafayette Section; O. Kiltie, chairman, Fort Wayne Section; F. R. Finehout, secretary, Indianapolis-Lafayette Section; and D. H. Hanson, secretary, Fort Wayne Section. The vice chairman, District secretary, and chairman of the District committee on Student activities are ex-officio members of the coördinating committee.

Reports were presented by Section officers in which the activities of their respective Sections during the past year were described and plans for the coming year were outlined.

The desirability of increasing the territory of certain Sections, due to the larger distances which can be traveled easily with modern means of transportation, was discussed. A number of questions regarding the value of Institute membership and the nature of the activities of the Institute and organizations with which it is related were brought up. In particular, questions were raised regarding American Engineering Council, and the schedule of Institute dues. It was decided that additional information on these subjects should be obtained from Institute headquarters and the board of directors.

Mercury Vapor Turbines at Kearny Station



THE mercury vapor boiler and turbine-generator installation at Kearny (N. J.) generating station of the Public Service Electric and Gas Company may be inspected by those attending the Institute's forthcoming winter convention in New York, N. Y., January 22–25, 1935. This installation is reported to represent the most efficient cycle which has been developed to generate electricity. The turbine end of Number 1 mercury unit is shown here. The electric generator which it drives is not visible in this picture, as it is on the other side of the unit. 20,000 kw capacity is available from the generator, and, through the production of superheated steam which is utilized in steam turbine units, an additional 33,000 kw capacity is produced by the mercury boiler.

Honorary Members Elected by Japanese Institute

Honorary membership in the Institute of Electrical Engineers of Japan (the "Denk-Gakkwai") was bestowed upon Dr. Frank B. Jewett (A'03, M'10, F'12, and past president) vice president of the American Telephone and Telegraph Company, and president of the Bell Telephone Laboratories, Inc., and to Dr. Irving Langmuir, associate director of the research laboratory of the General Electric Company, Schenectady, N. Y. The election of Doctor Jewett and Doctor Langmuir to honorary membership was made at the officers' conference of the Institute of Electrical Engineers of Japan at its meeting held October 18, 1934. The ceremony for the awarding of the diploma and badge of honorary membership was held on November 7.

On this date, Doctor Langmuir gave his first lecture under the Iwadare Foundation. The Iwadare Foundation, under the trusteeship of the Institute of Electrical Engineers of Japan, provides means for promising Japanese students to study in the United States, and also provides means for bringing to Japan noted American electrical engineers as lecturers. Doctor Langmuir is the

third Iwadare lecturer from the United States. The A.I.E.E. committee on the Iwadare Foundation, which selects the lecturers and assists the Japanese students in this country has, since its inception in 1931, been under the chairmanship of Doctor Jewett. At the presentation ceremony, Doctor Langmuir received the diploma and badge on behalf of Doctor Jewett.

Doctor Langmuir was born in Brooklyn, N. Y., January 31, 1881. He graduated from Columbia University in 1903 with the degree of metallurgical engineer, and 3 years later received the degree of doctor of philosophy from the University of Göttingen. Returning to the United States in 1906, he became instructor in chemistry at the Stevens Institute of Technology, and 3 years later entered the research laboratory of the General Electric Company where he is now associate director. Doctor Langmuir's researches have been conducted in the fields of chemistry, physics, and engineering, and through his pioneer investigations he has been successful in opening up these fields in many new directions. His chemical researches have been directed largely toward deriving from the phenomena of physical and organic chemistry the underlying principles of the atomic and molecular mechanisms which give rise to these phenomena. In the field of physics he has done much pioneer work in electronics. He also has been actively engaged in a number of auxiliary lines of research which have contributed to the success of vacuum tube production. Among the best known of his inventions are the gas-filled incandescent lamp, and the atomic hydrogen arc welding process. He has been the recipient of many prizes and medals, and also of a number of honorary degrees; in 1932 he was given the Nobel prize in chemistry.

A brief biographical sketch of Doctor Jewett's career is given in the "Personal Items" on p. 140 of this issue.

The honorary members from countries other than Japan, and the dates of their election, are as follows:

1929	Thomas A. Edison (A'84, M'84, HM'28, and member for life). (*Deceased*, 1931.)
1929	Elmer A. Sperry (A'84, M'93, and member for life). (*Deceased*, 1930.)
1929	Carl Köttgen.
1931	Arthur E. Kennelly (A'88, M'99, F'13, HM'33, Life Member, and past president).
1933	Guglielmo Marconi (HM'17).
1934	Frank B. Jewett (A'03, M'10, F'12, and past president).
1934	Irving Langmuir.

The Engineering Societies Library

In the last issue of Electrical Engineering (December 1934, pages 1666–7) an article appeared describing one of the agencies in which the Institute and its members are interested, namely, American Engineering Council. References to 3 other articles giving information on the Institute and the agencies related to it were contained in the "Membership" item on page 1664 of the December 1934 issue. Supplementing these articles, the following article on the Engineering Societies Library has been prepared by Prof. W. I. Slichter (A'00, M'03, F'12, and national treasurer) chairman of the library board:

The Engineering Societies Library

The members of the American Institute of Electrical Engineers may justifiably be proud of their library and for their own benefit should become better acquainted with the service it can render them.

The Engineering Societies Library is the property of the 4 national societies of civil, mining and metallurgical, mechanical, and

Radio Broadcast Station KYW Moves Into New Quarters at Philadelphia

On December 3, 1934, Westinghouse radio station KYW began broadcasting from its new facilities in Philadelphia, Pa., on a frequency of 1,020 kilocycles per second. Prior to that time, the station was located at Chicago, Ill., the first program having been broadcast from there in 1921. The new transmitter, which is shown in the accompanying illustration, is at Whitemarsh, Pa., a few miles north of Philadelphia; although designed as a 50 kw station, it will operate initially at 10 kw. The design of the station is notable for its compactness. Two features that resulted in saving much space are the use of extremely compact nitrogen-filled radio capacitors and a high voltage rectifier of new design. Foremost among the other technical innovations of the station are its directional antenna system, the use of alternating current for all transmitting tube filaments, and the use of a cathode ray oscilloscope for monitoring.

The antenna system consists of 4 245-foot vertical masts each connected separately to the transmitter; by controlling the phase relationship of the current delivered to these 4 masts it is possible to adjust accurately the direction of the radio beam so that maximum signal will be delivered into Philadelphia and Allentown, Pa., and minimum signal in other directions where, if a signal were present, interference might result with other radio stations. Each mast consists of a 200 foot length of telescopic steel tubing mounted on insulators at the top of a wooden framework tower 45 feet high. A specially designed counterpoise is used to improve the ground system; this consists of a total of about 55,000 feet of copper wire formed into special cages which are suspended horizontally between insulators on poles at a height of 10 feet above the ground around the bases of the 4 antenna masts.

This new station is said to be the first high power broadcasting station to use alternating current for the filaments of all transmitting tubes. To neutralize the noise thus introduced into the transmitting system, a "magnetron suppressor" has been developed; through the use of this device, a current of proper phase relation, wave shape, and amplitude is delivered to the plate circuit of the radio power amplifier in opposition to the ripple produced by the alternating current on the filament. Power is obtained from 4,150-volt 3-phase 60-cycle distribution circuits.

electrical engineers, and is maintained by funds contributed by these societies, a contribution which amounts to 58 cents per year per member of the A.I.E.E. This library contains a vast fund of very valuable engineering material and may be considered the depository of the valuables handed down to us by preceding generations of engineers. But it is not only a depository of information, it is also a working laboratory of information because expert specialists are working continuously to make this information available to all. The library has been so indexed that there are available some 476,000 cards bearing almost every item of engineering topic that can be suggested, and directions to where that knowledge may be found on the shelves of the library. This information may be obtained by visitors by a reference to the card catalogue which is arranged so as to be very easily understood, but in many cases the information is given by the staff by letter or telephone as the result of hurried requests. These requests cover a wide range of questions, from simple questions that may be answered by a note, such as "What is a tester coil?"—"What does mho mean?"—"Where can I find the consumers voltage in Berlin?"—"Where was Steinmetz born?"—"Where is there a description of the Dnieprestroy plant?"—to questions which involve an elaborate study and many pages of report either in the form of bibliographies, translations, or photostatic copies of the original articles.

It is interesting to note that during the past years of depression the work of the library has very much increased, as many persons having time on their hands have devoted this time to develop ideas to which they did not have time to give much study in the busy days, and others who are out of employment considered the best use they could make of their time was to improve their education by study. Last year 32,000 individuals visited the library in person and there were 10,000 requests for information by mail or telephone.

In spite of this increase in use of the library the budget has been decreased 33 per cent since 1930 and is now at the lowest figure it has been since 1919. The library is under the control of a board having representatives from each of the 4 above mentioned founder societies and this board takes its responsibilities very seriously and is endeavoring to manage our library so that each of the 50,000 members of the 4 societies will receive service when he turns to the library, and so that the collection of books will continue to grow and therefore include the latest books on every subject. In addition it is necessary to keep up the work of binding because new periodicals are always being added to the collection and must be bound to be useful, and many of the books are used so much that they have to be rebound every few years.

We possess about 145,000 volumes and this is probably the best collection of engineering literature in the country, and one to which not only all engineers should look for published information on any technical subject but to which some of the other libraries in the city also look for information which is not available on their shelves.

In the December 1934 number of Electrical Engineering, pages 1668–9, there appeared an article describing the searches and bibliographies, and listing some of those which would be most interesting to electrical engineers. This gives some idea of the requests which we have had in the past, of the character of work which is being done, and the suggestion that many engineers could use this service with profit to themselves. It is the sincere desire of the library board to keep the library in condition to be of greatest service to the members of the societies which own it.

Finding Work*

The second and concluding section of an authoritative dissertation dealing in a practical way with the important problem of finding work, and keeping it after it is found, is presented herewith. This article, the first section of which was published in Electrical Engineering for December 1934, pages 1670–4, was written by Samuel S. Board, placement specialist of New York, N. Y., for The American Society of Mechanical Engineers.

Planning a Job Campaign

PERHAPS engineers will be inclined to say—if they get this far—"Now at last we are getting down to something important." But if the preceding discussion has not been read carefully, what follows will probably be of much less use. You cannot plan a job campaign unless you know something about yourself and about the field of work you are approaching.

The first step in planning a sales campaign for yourself is the preparation of a statement of your record. A man came in the other day bearing a large folio-size volume, leather-covered, and 2 inches thick. It was filled with data about himself, his picture, letters of recommendation, even articles he had written, and yet to me it was almost a complete waste of effort since it was not assembled in an intelligent order. It had no index and there was no brief summary of the man's career or of what he could do. In any but the most exceptional cases, a one-page summary would have been far more effective.

Many plans have been outlined for preparing such statements and great things have been claimed for some of them, but rather than give an exact form, I am going to suggest certain principles. If you have made the personal analysis previously outlined, this is all that will be necessary. Be sure, however, to eliminate most of the details you have accumulated and make the result a summary.

In the first place, any such statement should contain a statement as to what you want to do, even if this has to be changed a dozen times in applying for a dozen different jobs. If you do not want to include this with the rest of the summary, it should be on an attached sheet or in an accompanying letter. How to determine this has been discussed previously. In the second place, it should contain a consecutive chronological experience record. There is no substitute for this. Recently, many men have tried to emphasize their abilities by describing functions they have performed without indicating how long ago they were performed and for how long a period. Such an analysis is of value and frequently helps the man, but it does not satisfy the employer unless, at the same time, he is given an idea as to when and how it was done. Also, I think it is helpful with most employers to have a picture of the flow of a man's experience. Engineers who are hiring men seem to like this experience record presented in chronological order, but other employers prefer to know what the man's recent experience has been and give it more satisfactory attention when it is described in the reverse order. It is really better selling to present it this way also, since, otherwise, the reader is likely to give too much attention to the time the applicant was an apprentice or an office boy.

Finally, such a record should be rounded out by giving details which will complete the picture of the applicant as a man—his birth, education, family status, interests, and habits.

Of course, the physical make-up of the summary must be varied to suit conditions, depending on whether it is to be used in a letter or presented in person, but it is desirable in any case to have it written out. It is easier to present verbally, it reinforces the applicant's case afterward, and it seems to act as a reminder.

If it is to be used for such a purpose it should be typed or printed with a pen, well laid out on good paper, and as concise as possible. Many times such a record can be condensed to one sheet of paper. At the most it should not be more than 2 pages long.

There was a time when booklets or brochures were uncommon enough so that employers would read them through, but, un-

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less they are brief and extraordinarily well done, employers now are likely to look at the first page rather carefully, glance at the second, and thumb the rest. It does no good to write a nice story if it is not read.

Perhaps a word should be said about references. The general reference is so much abused in this country that it is of little use except to verify dates and duties. Employers wish rather to have the privilege of consulting the people themselves for whom the applicant has worked. Occasionally, a letter written by a former employer to some other person may be used, but even this is not given as much credence as a fresh inquiry. On this account such opportunities to refer to busy men should be used sparingly and only when a real job is in prospect. In many European countries, including Germany, the Scandinavian countries, and, I think, France, a man carries with him what amounts to a dossier—a complete record of his former employment with formal letters of reference—and such papers can usually be accepted at their face value, but the English follow a system much like our own.

Where to Look for a Job

After you have armed yourself with a summary of your experience and a decision as to what you wish to do, the next question is where you are to find a job. To do this (unless you quite literally create it) the surest way is to study the areas of opportunity. Given the abilities and interests you have, where can you find the opportunities to use them? You should have settled the question as to the functional part you want to pursue and know whether it is production, sales, or control, and then, within what type of business.

Suppose you are an operating man and wish to go into factory work. Shall it be steel or glass or textiles or shoes or machinery or automobiles? You must pick a field or fields—1, 2, 3, or more. The field should be located within the geographical area accessible to you and in which you want to work. It ought to have at least the possibility of being busy shortly. The business ought to be such an essential one that it cannot be discontinued and be in fair shape financially. Preferably it should not be popular or have glamour, like airplane manufacturing, else you will be elbowed by a horde seeking the same thing.

The next question is, do they use engineers? If they do not, could they? Perhaps you can sell them the idea.

There are more questions one could ask about the field, such as the limits of its rates of pay, the overcrowding of its ranks with technical men, and so on, but those already mentioned are fundamental. Where can you get this information? Any good newspaper, for one source; also from technical and financial magazines, from discussions with business men, and from the list of dividends paid or omitted.

Having selected 3 or 4 fields, the next step is to find in these fields specific companies whose policies are sound, whose product is well made, whose finances are not too involved, and whose affairs are not marked with an excess of internal friction. How can you find out these things? From the financial directories, from leaders in the field, from your bank, and from men who have formerly worked for the companies. All this information should be recorded, tabulated, and sorted, so that you can make a list of companies in order of the desirability of work with them, and then proceed to cover that list. Doing it in person is best—by letter, if there is no other way.

You must go after something *definite*, however. Don't just ask for a job. Tell your prospective employer that you wish to work for him and what you can do.

Finding and Holding a Position

A Check List for a Standard Technique

In Looking for a Job:

- Write out an experience record .... ☐
- Analyze it according to functions .... ☐
- List your personal qualifications .... ☐
- Combine these into an effective record for presentation .... ☐
- Decide on functions you have performed best and liked best .... ☐
- Decide on geographical location .... ☐
- Select fields or areas of work, such as industries .... ☐
- List desirable employers in these fields of work .... ☐
- Plan your approach: (1) In person ☐ (2) By mail ☐ (3) Otherwise ☐
- Follow up your contacts .... ☐
- Restudy your technique (in light of last 2 items) .... ☐

After You Get a Job:

- Analyze your job .... ☐
- Study the jobs that lie ahead of you ..... ☐
- Study your coworkers .... ☐
- Make outside acquaintances .... ☐
- Develop your social life .... ☐
- Plan your reading .... ☐
- Join professional organizations .... ☐
- Study allied fields .... ☐
- Plan and develop hobbies .... ☐

I'm talking, I know, to men, many of whom have been looking for weeks and months and even years—tired, discouraged, and disheartened—but, men, we must "sell them a bill of goods!" Many of you have just been asking for jobs. Others haven't been doing even that. They have been calling on acquaintances and wistfully asking them if they know of anything. What they forget is that they *have* something to sell—brains, experience, drive, enthusiasm, determination, even brawn, if necessary. We must not be apologetic or ashamed but *sure* that we have something to offer.

Several years ago I had a boss whom I still consider a typical example of the better type of business man and I learned quite a bit about selling ideas from him. I found that if I went down to see him in the afternoon and put an idea before him with pros and cons but without urging a favorable decision the answer was likely to be "no," but if I waited till the morning, took care to be well-groomed, entered alertly, explained the proposition, and said, "I think we ought to do thus and so," the answer was, "Go ahead." He wanted me to believe in it first. Lots of college men out of work have come to my office this summer. Some I have helped to get work, many are still looking, but there was one boy who stood out. He was a little under medium height, good looking in a way, but with no special attractiveness of that sort. However, when he came in he *knew* what he wanted to do. He presented his desires briefly but enthusiastically. He acted on suggestions promptly. The field he entered has been overcrowded and was dull at the time, but in 2 weeks he had 3 jobs lined up, and, naturally, he took 1. It isn't so easy with older men, since there are fewer jobs and the requirements are likely to be more definite, but the approach makes a world of difference.

There are other ways of finding work. No one should be ashamed of using the help of friends, if it is offered, but you should help them by making clear what they can do to help. There are also employment agencies, public and private, good and bad. Despite the opinion of many, good opportunities are to be found that way. You should, of course, be listed with your professional society. There are the advertisements in the newspapers. These bring a lot of heartaches, however, unless you learn to discriminate between them and are willing to write repeatedly without having extended to you the courtesy of a reply. In reply to inquiries your letter should be as brief as possible. It should give the information asked. It should be carefully typed or printed (if you do hand-lettering easily and well) and set up so as to stand out for its neatness and clarity.

There are some good blind advertisements; but the chances are better of its being a genuine and desirable job if the firm's name and address are given. Blind advertisements are like blind dates—occasionally a "honey" but usually "sour."

Many men ask me about writing letters—letter campaigns—and about following up personal or letter applications. My experience has been that in good times letter campaigns are very useful. Frequently, we can get results from them (if the applicant is employed and wants a better job, for instance) through a third party, but in these times the only campaigns worth mentioning are those carried on in the name of the man himself to individuals instead of firms, and by means of individually typed letters *very* well done. Even these will sometimes bring a lot of nice replies without anything favorable. The writing of letters, however, by agencies and organizations has almost approached the stage of a racket, and in many places has spoiled this medium of getting jobs. As to follow up, you must strike a happy medium. It certainly doesn't do to let a favorable lead go too long unacted upon, but you must be careful not to arouse resentment by writing unnecessarily. Two-week intervals are about the right length in most cases, unless you are asked to do otherwise.

The Salary Question

One of the most important matters to be decided in applying in person or by mail is the amount of the salary. If you can, and unless you know the rate the employer desires to pay, it is better to get him to make an offer which you can accept or try to raise as you think fit. If you *must* name a price, make it fit the job. It is no use asking too much for a minor job and it is foolish to ask too little for a good one. Even in these times I have known employers to turn men down because they were too eager for the job and have asked too little.

The first thing in determining a fair price is the value of the work to be done. If you can, find out what others are getting. Ask about standard prices in employment agencies; but find out if you can the *going* price for such work. Next, you should consider the policy of the company in question. Is it tight or liberal, prosperous or broke? It is foolish to ask as high wages of a company that is having rough going instead of having a nest egg in the bank. The third factor is the impression you make. If the price is not fixed, you can count on a difference of at least 30 per cent between the wage paid a man who is diffident or seedy or somewhat beaten and the man who is "on his toes" and confident of himself. Sometimes a man will have a big "front" with nothing behind it, but I don't know why a man who can do the work should not act as if he himself believed he could.

College men, as a whole, have been accused quite generally of thinking too well of themselves. After having worked with them for several years I should say the reverse is true, but engineers never could be accused of it. They may know the value of steel and brass and tools, but when it comes to themselves, the rule doesn't hold. Some day we may have a code of fair salaries for technical men, but in the meantime you must be your own appraiser.

Closing the Deal

Finally, it is necessary to learn how to "close the deal." It has been mentioned already that "signing on the dotted line" is the equivalent of this for most salesmen, and it is the critical point of any salesman's effort. The only satisfactory way to do this is to create a desire and then leave it unsatisfied until the agreement is reached.

A very able salesman, who was one of my mentors years ago, told me repeatedly, "Sam, more men oversell than undersell. If they only knew when to stop talking, they would have a better chance to close the deal."

Back in 1929 an engineer who was working at something he didn't like came to me and asked me to get him a technical job. I put him in touch with half a dozen over a 2-year period and he "muffed" them all. Finally, in 1930, after the depression had hit us, a position became open near his home. It involved a good salary and it was something I thought he could do. It seemed as if this were *the* chance, so I called him in and made him apply to me for a job. Then we analyzed his technique together. There seemed to be 2 troubles: First, he was not well enough prepared, and, second, he didn't know how to close the deal. In order to remedy the first difficulty I sent him down to a friend of his who was doing similar work and he (the friend) generously told the man all he could about the job. Then he went home, at my suggestion, and boiled down all his experience and his ideas about the job to a 20 minute presentation. I told him, "When a pause comes in the interview, tell your story, not like a canned speech but genuinely, as it applies to that situation. When you finish you may find another pause. If you do, get up and *leave*." He followed instructions. A committee of 4 men interviewed him and they asked a few questions. There came a pause and he said to himself (as he told me later), "Well here's where I shoot the works." He did so and again there was a pause, so he arose and said, "Well, gentlemen, if you want me you can get me on the 'phone." They called him up at 9 that night to make sure they would not lose him.

Personnel men sometimes have to be treated differently. They have certain questions to ask and will not be denied, but if you know your story you'll probably know the answers. In any event, *you* terminate the interview. Numbers of men visit my office every day. Only a very few know enough to terminate the interview, and if I try to tell them and intimate that

A Reading List for Junior Engineers

A LIST of books recommended for reading by junior engineers has been prepared by a number of eminent men, many of them distinguished in the engineering profession. One section of this list, that on "natural science," was published in the December 1934 issue of Electrical Engineering, page 1667. Two other sections are published herewith, and others are scheduled to follow in subsequent issues. The complete list includes more than 100 titles.

Systematic reading of worth while books adds breadth and vision to the background of an engineer and should be considered a part of the intellectual development designed to fit the young engineer for full professional recognition. It is suggested that over a period of about 4 years a minimum of about 25 of these books might be selected and read, with the limiting recommendation that the selection made will include at least one book in each classification, preferably in accord with the individual engineer's most vital interests.

Philosophy and Religion

This Believing World, Lewis Browne. Macmillan, 1930. A fascinating account of the development of the chief modern religions.

Meaning of Right and Wrong, R. C. Cabot. Macmillan, 1933. Discussion of the characteristics of right and wrong conduct as related to ordinary human experience, for people unfamiliar with philosophy.

Philosophy and Civilization, John Dewey. Minton, 1931. Might be described as "essays in experimental psychology." Form is more readable than that of his earlier books.

Dance of Life, Havelock Ellis. Houghton, Mifflin, 1925. Author's philosophy of life as an art. From a study of dancing as an essential and primary art, the theme is expanded through a consideration of the arts of thinking, writing, religion, and morals.

Types of Philosophy, W. E. Hocking. Scribner, 1929. History of the leading types of philosophy, with thorough comparative analysis. Intended for beginners in philosophical study.

Effective Thinking, Joseph Jastrow. Simon and Schuster, 1931. An informal account of thinking. Part 1 deals with the technique of thinking; part 2 with impediments to clear thinking; part 3 with constructive phases by which right thinking is guided and encouraged.

Humanism and Science. C. J. Keyser. Columbia University Press, 1931. Evaluation of science and mathematics as agencies for realizing the ideals of humanism.

Education and the Good Life, Bertrand Russell. Boni and Liveright, 1926. Stimulating book, full of common sense and practical advice. Deals with postulates and aims of education, education of character, and intellectual education through university years.

The Coming Religion, Nathaniel Schmidt. Macmillan, 1930. Survey of origin and development of religion to our time, and search for the direction in which religion is moving today. Author is professor of semitic languages at Cornell University.

Misuse of Mind, Karin Stephen. Harcourt, Brace, 1922. This book is likely to open one's mind to unexpected possibilities; an excellent introduction to the philosophy of Bergson.

Imitation of Christ, Thomas a Kempis. Macmillan, 1924. For 5 centuries the Christian manual. Expresses with simplicity yearning of the devoted worshipper for communion with God and Christ. Offers ethical counsel and personal guidance and is an unfailing source of comfort and inspiration.

Psychology

Psychology at Work, P. S. Achilles, et al. McGraw-Hill, 1932. Material derived from a series of lectures arranged by the Psychological Corporation in 1931; gives a good idea of a few things being done today in the broad field of applied psychology.

Everman's Psychology, Sir John Adams. Doubleday, 1929. Book of applied psychology written in terms the layman can readily understand. Recent psychological tendencies and schools are presented, question of individual adjustment taken up, and studies of emotion and instinct as applied to individual development discussed.

Human Traits and Their Social Significance, Irwin Edman. Houghton, Mifflin, 1920. Introduction to contemporary civilization. Processes of human nature from man's simple inborn impulses and needs to their most complete fulfillment in relation to art, science, and morals.

Man as Psychology Sees Him, E. S. Robinson. Macmillan, 1932. Man, and comments on his nature; psychology, its aims; a lucid exposition of what psychology is accomplishing in helping man to self-understanding.

Psychology for Executives, Elliott Dunlap Smith. Harper, 1928. Deals with themes such as habits and how to handle them, personality, self control, and the effect of group psychology in industry.

Industrial Psychology, Morris Viteles. W. W. Norton, 1932. An attempt to present a comprehensive picture of modern industrial psychology in its applications, principally in Germany, France, England, Italy, etc., from its inception about 20 years ago, its problems, settings, findings, and accomplishments.

they are taking too much time, they either get scared or feel hurt. I often wonder why.

LOOKING AHEAD WHILE WORKING

There remain 2 related topics which are pertinent. The first is concerned with the time when you have a job. Many men seem to follow the reasoning of the old farmer who was taxed with the leaks in his roof. "Why don't you fix them, John?" he was asked, "It wouldn't be much work." "Wall," he said, "When it's raining tain't possible, when tain't, tain't necessary." No one can be so sure of his position that he does not need to do 2 things: First, to study the possibilities in his present position, and, second, keep in touch with outside activities.

Many men go on the theory that if they do a good job that is all that is necessary, but nothing could be more mistaken. Other people may not be doing a good job, the company may be losing its market, policies may change, top management may change, and with it changes the whole picture which looked so rosy when you started. You may also lose opportunities for 2 reasons, first, because you have no one to take your place, and, second, because you do not know what is required in the job above you. Some time ago a man was brought in from the outside to fill an executive position when there was an old employee in the place just below, apparently fitted for the job. It seemed so unfair on the part of the company that ordinarily was decent that I took pains to find out the reason and was told that the only reason was that the old employee had not learned to speak in public, whereas the job required, incidentally perhaps, attendance at conferences and meetings where the company needed a spokesman. This is not an advertisement for public-speaking courses, but the incident is told because comparatively little things so often handicap a man unnecessarily.

There is insurance from many angles also in keeping in touch with the outside. It is not necessary always to be yearning for some other kind of a job, but neither does it hurt to keep your abilities before others. This is especially true for engineers who work on specific jobs, be it a bridge, or a factory survey, or the installation of new machinery. How can this be done? Well, it is considered bad form in some circles of society to talk about your job but among men it's always permissible if your description isn't extended unduly. Men like to know what others are doing, but if you talk about your work you must also give others a chance to talk about theirs. You needn't talk much about yourself in doing this and you shouldn't, but your job is another matter.

Beyond this, every one should keep in touch through reading, through conversation, and through professional meetings, with new developments. It is necessary for growth.

Keeping in touch with other businesses and new developments does not necessarily imply leaving your old concern. A highly successful employee of one of our largest corporations confessed that he did not really start to go up until he had had a good offer from another firm and turned it down. Many men have had that experience, but this man let his firm know and it was not long before he was advanced.

PROFESSIONAL ADVANCEMENT

The foregoing applies to most men who work for others, but engineers have both an excuse and means offered them for doing it in that they belong to what is generally called a profession. I will not attempt to define a profession here, but it does imply, as is the fact, that there are others of similar training and experience and that these have joined together to study common problems, to develop standards of training and performance, and to safeguard the ethical bases of the occupation.

I have known men who derided or ignored their professional societies, although, I am glad to say, not frequently; but these organizations are really of tremendous benefit in stimulating new thinking, in providing a common meeting ground for men of like interests, and in the establishment, even though sometimes in an elementary fashion, of standards of performance and training.

Moreover, they are a big help in making possible the professional and intellectual growth without which a man of professional status will retrogress. There is no such thing as standing still. Either we keep our minds active and flexible and keep abreast of new developments, or we fall behind. It is not easy to keep reading new professional literature, especially after a hard day's work. Neither is it always a pleasure to attend meetings, when they are not concerned with our particular tasks, but new ideas come that way—encouragement from the experience of others, facts which are useful when we least expect them.

It may seem a little ironic to go from this to social pleasures but social activities are also important, especially if they take the form of relaxation. Here again it is a case of keeping your mind flexible and adaptable as well as learning to deal with people.

I am not going to duplicate the endless success stories it is possible to read, but a well-rounded man is more able to meet new emergencies, and, regardless of what we would like to believe, social activities have been the means of advancement of a host of men. Professional integrity and eminence need not be sacrificed to social eminence, but social contact, sports, hobbies, amateur public service, all offer the means to meet and know others and are enjoyable in themselves.

A good deal of nonsense has been said and written about the development of personality, as if you could have your personality "lifted" like your face; but, as we are affected by our environment, we learn to talk with others easily and more fluently, and we should, but sometimes do not, learn the lesson of tolerance.

Some men will come into a room or an office and will immediately make an impression. They seem to have a little something that sets them apart, that makes others remember their names. It isn't height or weight or ugliness or beauty, despite all the advertisements. It's a man's sureness of himself or his individuality that distinguishes him from the rest of the herd. Such a man finds opportunity because he is remembered. Do people say about you, "What was the name of that man we saw last Friday?" or do they say, "Remember that man Jones we saw last Friday?" It's very much up to you; and your career, if not your happiness, may depend on it.

Engineering Foundation

Officers Elected by Engineering Foundation

At a meeting of the board of the Engineering Foundation the following were elected to fill the unexpired portion of terms of members of the board ending on February 21, 1935:

Chairman: H. P. Charlesworth (M'22, F'28, and junior past president), American Institute of Electrical Engineers; assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y.
First Vice Chairman: D. Robert Yarnall, The American Society of Mechanical Engineers; member of firm, Yarnall-Waring Company, Philadelphia, Pa.
Second Vice Chairman: Edwards R. Fish, member-at-large; The American Society of Mechanical Engineers; Hartford Steam Boiler Inspection and Insurance Company, chief engineer, Boiler Division, Hartford, Conn.
Representative on National Research Council: H. P. Charlesworth.
Additional member of executive committee: Otis E. Hovey, American Society of Civil Engineers; also member, A.S.M.E., consulting engineer, American Bridge Company, New York, N. Y.

Standards

A.S.A. Reëlects Officers for 1935

Howard Coonley, president of the Walworth Company, was reëlected president of the American Standards Association for 1935, at the annual meeting of the organization held in New York, N. Y., December 12, 1934. Frederick E. Moskovics, representing the Society of Automotive Engineers, was reëlected vice president. Mr. Coonley, who represents The American Society of Mechanical Engineers, has served 2 terms as president.

J. C. Irwin, Boston and Albany Railroad, and F. M. FARMER (A'02, F'13) vice president and chief engineer of the Electrical Testing Laboratories, New York, N. Y., were reëlected chairman and vice chairman, respectively, of Standards council.

During 1934, 22 new American Standards of interest to the lumber, jewelry, pipe, gas and gas appliance, electrical, paper, textile, petroleum, and construction industries were approved by the Association. During 1934 the Association reached an all-time peak in membership, with 47 member-bodies and associate members, representing 52 national organizations and 1244 company members.

New members of the Standards council representing member-bodies of the Association, who were introduced at the December 12 meeting, were R. P. Anderson, American Petroleum Institute; D. A. Zimmer, division of safety, U.S. Labor Department; Col. John Mather, War Department; and

O. B. Blackwell (A'08, F'17) of the American Telephone and Telegraph Company, New York, N. Y., who represents the telephone group.

American Engineering Council

A.E.C. to Hold Annual Meeting

The Annual Meeting of American Engineering Council in Washington, D. C., January 10–12, 1935, comes at a period likely to approach an all-time high for Washington activity. The present lull will break into a long-pent rush of action as Congress and the top Federal officials line up the program for 1935. If organized engineers are to have any say in the shaping of these events, mid-January is the time to make themselves heard.

The annual meeting, therefore, finds itself in the midst of a situation wherein the scope and direction of the recovery program are of first interest. What part are engineers to play as executives, planners, technical workers, and builders under the government? What can they offer in the way of constructive criticism? What are the new public responsibilities of organized engineers? This meeting proposes to make a careful review of the facts so that all may get a sense of direction and be guided thereby.

Committee meetings of Council, and conferences of engineering society secretaries, are to be held on Thursday, January 10. On Friday, January 11, there will be a symposium by officials of the major Federal units who are invited to appear before the Assembly of Council for frank discussion of their objectives, on the relations of government to engineering development. A dinner will be held in the evening.

On Saturday there will be development by the Assembly of continuing programs as influenced by the proceedings of the previous day.

All sessions will be held in the Pan American Room of the Mayflower Hotel, Washington, D. C., starting 10:00 a.m., January 10. Acceptances are being received in gratifying number from the secretaries of engineering societies throughout the country, all of whom are invited to attend.

Resources Board Report Shows Federal Trends

The outlook for further extension of the recovery program in fields of most interest to engineers begins to shape itself in the report of the National Resources Board to the President December 1. A permanent Public Works Administration with broad powers for the planning and execution of Federal projects is among the principal recommendations. It is proposed also to set up permanent groups for national planning under the National Resources Board, with sections specializing in land, water, and other phases of the program.

Planning is the keynote of the report which includes a "plan for planning"—for coördinating the coördinators. Systematic development of water resources is discussed in terms of power, sanitation, flood control, reclamation, and other uses. Suggested land policies include eliminating production on marginal areas, control of soil erosion, and conservation of minerals. Under these headings, the recommendations call mainly for further studies rather than dealing at once with the scope and cost of the final work.

Little can be done to advance the sections of the report of concern to engineers until it is known how far the Administration will go toward pushing such plans. Meanwhile the unqualified and specific recommendations with regard to survey items give some measure of assurance that the Federal responsibilities of engineers will be augmented during the present session of Congress.

Census of Engineers

The U.S. labor department survey of the engineering profession is rapidly taking form. Questionnaires, up for final approval before the (Federal) Central Statistical Board, will go out as soon as the mailing list is completed. (See Electrical Engineering, December 1934, page 1677, for details.)

Dr. Isador Lubin, director of the Bureau of Labor Statistics, making the survey in coöperation with Council and member societies, has this to say: "Checking up on the status of engineers is one of the steps toward a better understanding of the problems surrounding the professional and white collar workers in general. . . .If anyone can make immediate and practical use of statistics, it ought to be the engineers. So we are seeking to provide some of the basic figures to this group. . .in order that they may analyze their problem without any guesswork as to the actual trends and conditions. . . .In dealing with professional people, it is believed that we can secure an unusually high return as to accuracy and completeness."

Directory of Engineering Societies

A directory of 236 engineering societies—national, state, and local—has been compiled through questionnaires under the auspices of American Engineering Council, the Engineering Foundation, and the Engineering Council for Professional Development. To be issued early in the year, the booklet includes names of officers, type and number of members, publications, dates of annual meetings, etc. Copies may be ordered at 50 cents each from American Engineering Council, 744 Jackson Place, Washington, D. C. Please send orders promptly so that the printing schedule may be arranged accordingly. Payment in advance will help cut billing costs.

Letters to the Editor

Overcompounded D-C Generators in Parallel Without an Equalizer

To the Editor:

In the November 1934, issue of Electrical Engineering, pages 1553–4 appears a "Letter to the Editor" in which Prof. O. W. Walter takes issue with Dr. Harold Pender and me. The problem under discussion is one concerned with the operation of overcompounded d-c generators in parallel without an equalizer. Mr. Walter believes he has shown "the unsoundness of (the) reasoning" used by Dr. Pender in his book "Direct Current Machinery" and states that others have obtained experimental results contradicting those given by me (Electrical Engineering, October 1932, p. 745).

It is the purpose of this reply to point out that Mr. Walter and the persons to whom he refers have not disproved or contradicted either the theoretical or experimental results he attacks, for the simple reason that he is not discussing the problem we were. In order to make this clear, the following is quoted from the October 1932 note referred to above, in which were given oscillograms showing, for a given generator, *speed increasing* and current simultaneously decreasing:

"The problem is not of importance practically but has considerable theoretical interest, as has been evidenced by the discussion aroused by the statement in 'Direct Current Machinery,' . . . . that for a given total line current, if the *speed* of one generator *increases* after the equalizer has been opened, the current output of that generator decreases, and, ...

"These oscillograms show conclusively

that the majority argument (contra Pender). . . . cannot be of universal application. It cannot be claimed, however, that the oscillograms prove completely the other (Pender) point of view. The problem is one which depends on many factors—the system would be unstable without an equalizer if the speeds remained constant—but the oscillogram of Fig. 3 does indicate that for the particular case the changes took place so slowly, comparatively, that the analysis using the steady state regulation curves would be expected to indicate at least qualitatively the action."

The following paragraphs are excerpted from Mr. Walter's note:

"The actual transient solution of the current . . . . . is not difficult. . . . . . By making certain simplifying approximations, solutions may be obtained which are helpful in visualizing the manner in which the current changes.

"As the simplest case, in Fig. 2 assume zero load current (each armature supplying only its shunt field current), constant shunt field currents, *and constant speeds*."

The situation is then this: Doctor Pender has given a theoretical argument based on the change *of speed* of a generator. I have presented experimental results consisting of oscillograms *of speed* and current, confirming Dr. Pender's argument.

Mr. Walter has discussed the case in which *the speed is held constant.*

Hence there is no comparison between the 2 cases.

For the benefit of anyone who cares to analyze the case considered by Dr. Pender and me, it may be suggested that the prime mover must be considered. In our work we have implicitly assumed a drooping speed-torque characteristic.

Yours very truly,

J. G. Brainerd (A'32)
(Assistant Professor, Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia)

New Uses for Overproduced Products

To the Editor:

I have read with great interest the speeches of Doctor Jordan and Colonel Chevalier delivered before the Institute in New York on October 10 (see Electrical Engineering for November 1934, page 1546–51), and I quite agree with practically all of the statements made by these gentlemen on that occasion. They have presented a masterly analysis of the situation, but I am also mindful that the national administration has on several occasions rather bitterly complained that while there is no dearth of criticism and analysis there have been no helpful suggestions pointing the way toward improved industrial conditions and the President has said that in case any of his pet schemes did not work out successfully they would be dropped forthwith in favor of something perhaps less drastic but more promising.

In view of the fact that the N.R.A. and A.A.A. for instance, have distinctly fizzled it may not be inopportune for the engineering fraternity to at least discuss and perhaps offer to the administration alternate schemes to be considered by those who happen to be directing recovery measures at the moment. As a starter may I offer the following idea in the rough:

One of the principal problems has been: "What shall we do about overproduction and dead stock?" We all know what the self-sufficient management tried to do in so far as agricultural products are concerned. As an alternative to the actions taken, may I suggest that the administration might better have considered: "What action would a large producer of any commodity take if he found he had on hand large surpluses of stock, especially raw material?" The answer, I think, is perfectly obvious. He would not only set up or employ an experimental station or laboratory and engage *practical* scientists to discover and develop new uses for his raw material just as the steel people, the aluminum people, and the plastic moulding people have done, but he would also concern himself very seriously with marketing and publicity measures.

Take the staple "cotton" for instance: It may not be generally known but cotton has many characteristics that have not been exploited to any considerable extent commercially. Pressed cotton is one of the best thermal and sound insulators known. Processed with the proper binding material it might be fabricated as slabs or boards for efficient heat and sound insulating purposes in buildings, cooling rooms, car insulation, etc. The uses of rubberized cotton fabrics may, no doubt, be multiplied in coverings, tenting, umbrellas, etc. "Washed cotton" has recently been proved to have very high electrical insulating qualities.

No one has yet found a satisfactory way to fire-proof cotton fabric but when this is done the field of application will be unlimited—curtains, drapes, sheetings, etc. When we take cognizance of what is going on in the field of metallurgy it seems but reasonable to suppose that any so called overproduction of the staple cotton might quickly be absorbed by worth-while products of a new type; quite certainly more economically than plain destruction and suppression.

As to wheat, the greatest of foodstuffs, almost any practical person can think of a number of ways of better disposal of this commodity than destruction and suppression. There are possibilities in beverages, confections, concentrated foods, etc., and the possibilities inherent in quality rather than quantity production.

As to the marketing phase: Where would you or I go today to purchase a few pounds of the grain in case we knew just how to prepare a delicious table food or beverage from it? The point of all of which is: Why is it not practical to discover the full value of our surplus stocks and consume them?

Whether or not some such plan as outlined above might have far reaching results, its adoption would at least have some effect in convincing the people that government measures are to be constructive rather than destructive, and this perhaps would be helpful.

Yours very truly,

B. D. Willis (M'32)
(Automatic Electric Co., 1033 W. Van Buren St., Chicago, Ill.)

A.I.E.E. Service to the Electrical Industry

To the Editor:

A man's knowledge and experience should be a source of great satisfaction to him but its value to others depends upon the use he makes of it. We are remembered by the thoughts we give to others and by our good deeds. Knowledge may be obtained from mathematical analysis and laboratory experiments by men who do not know how to put it to practical use. The analytical mind points out the reason why things happen but lacks the kind of imagination required to use this information to develop new and practical devices. The contributions to scientific knowledge sift down to commercial practice through several layers or stages of thought and practice.

The engineer who knows how to use new facts in design may not have the ability to select, without help from the application engineer and the enterpriser, articles that the public will buy. Sometimes we call the enterpriser a salesman, but the marketing of new products needs more than just salesmanship. The idea must first be presented to the public and the desire created before sales can be made.

Long after we knew how to design gas engines it took a Henry Ford to give the world an inexpensive automobile. Westinghouse visualized the use of alternating current when it was still unpopular and hard to use. Recently Daniel Willard gave us the air conditioned train and stimulated the demand for air conditioned rooms. Motor generator control was advocated by H. Ward-Leonard 25 years before the variable voltage elevator became a reality and made the modern installation in "Radio City" a possibility. The Diesel engine is old; its rapidly increasing use is due to the vision of men who invested time and money and patience in its commercial development. The electron tube emerged from the laboratory largely as a plaything; it was an interesting stunt to make the tube do something unusual. Gradually, practical use is being found for tubes as more people understand their use.

Sometimes we find persons who have the vision and ability to understand what the public would like to have, who know how to design and build it and then to market it, but usually better results are obtained through the coöperation of several persons. Greatness in individuals is as much due to their ability to recognize and use the talents of others as to their own ability to originate. Men of this kind become great leaders and enable others to find practical use for the knowledge which might otherwise remain locked within their own minds and useless to society.

One element of success is to give freely and wisely of our time to help others. Out of this effort will come contacts and ideas that will help us.

In this evolution of thought to practice the A.I.E.E. has a definite place. Those who complain that the Institute's publications are made up largely of papers that are of interest to the few and can't be understood by the membership at large forget that it and these authors are rendering a service to the profession that should be utilized more widely. It is not the func-

tion of the Institute to tell individuals and organizations how to make money. It tells them of the progress of knowledge in electrical engineering and it is for them to translate this knowledge into commercial uses through their engineers and enterprises. The Institute can best perform this service and it is one of the reasons for its existence. The business executive can't rest in quiet and content with things as they now are. Public demand is continually changing, commercial surveys are predicated on the past, not the future demand; alert business men are pressing for new things to sell; a successful business today may be outdistanced by competition and become bankrupt.

During the depression large business units have been forced on the defensive and had to retrench. Pioneering work has been dropped and, worst of all, many of their trained men with vision have left them but are still active. These men will increase competition in many novel ways and now constitute a threat to the profits of the older companies. The men who remain in these organizations should take an increasing interest in the Institute; it may be of great help to them.

Very truly yours,

H. D. James (A'98, F'12)
(Consulting Engineer, Gulf Building, Pittsburgh, Pa.)

Personal Items

E. B. Meyer Nominated for Presidency

Edward Barnard Meyer (A'05, M'13, F'27, and past vice president) vice president, United Engineers and Constructors, Inc., Newark, N. J., has been nominated for the presidency of the A.I.E.E. for the 1935–36 term. He was born October 22, 1882, at Newark. He received his technical education at the Newark Technical School, from which he graduated in 1901, and at Pratt Institute, Brooklyn, N. Y., where he graduated from the electrical engineering course in 1903. That same year, Mr. Meyer entered the employ of the Public Service Corporation of New Jersey as an engineering assistant, and remained continuously with that organization and its subsidiary companies until 1922. During this period he became, in 1906, field engineer in charge of the underground conduit and cable system; in 1909, assistant engineer on special engineering reports, estimates, and construction work; in 1912, assistant to the chief engineer; and in 1919, assistant chief engineer. With the formation in 1922 of the Public Service Production Company he was appointed its chief engineer. In 1929, Mr. Meyer was made a vice president of the Public Service Production Company, and in 1930, on the occasion of the merger of that company with United Engineers and Constructors, Inc., he was appointed a vice president of the latter corporation in the capacity of executive and engineering head of the Newark office. In addition to having been a director of the Institute, 1928–31, and later a vice president, 1932–34, Mr. Meyer has served on many of the Institute's committees. These committees are: executive, 1928–30, 1932–34; constitution and by-laws, 1929–35 (chairman 1934–35); coördination of Institute activities, 1925–35 (chairman 1932–34); Edison medal, 1927–29, 1930–36; finance, 1927–31, 1932–34 (chairman 1928–30, 1933–34); headquarters, 1928–30, 1933–34; Lamme medal, 1928–30; membership, 1924–25; award of Institute prizes, 1925–28, 1931–34 (chairman 1925–27); publication, 1923–35 (chairman 1927–28, 1931–34); Sections, 1926–27; technical program, 1918–29, 1932–34 (chairman 1925–27); transfers, 1932–35 (chairman 1932–33); power generation, 1928–32; and power transmission and distribution, 1918–24 (chairman 1918–23). He also has served on the special committees of Institute policies, 1931–33; Associate dues and related matters, 1932–35; and biographies and talking motion pictures, 1930–33. He has served as an Institute representative on the U.S. National Committee of the International Electrotechnical Commission, 1927–30; and on the Engineering Societies Monographs Committee, 1930–35; and the Engineer's National Relief Fund. He has also served on several of the Institute's subcommittees and on local Section committees, having been chairman of the New York Section, 1926–27. He was chairman of the Institute's 1932 winter convention committee. Mr. Meyer's other technical activities have included active participation in the affairs of the American Standards Association, the former National Electric Light Association, the New York Electrical Society, Inc., of which he is now first vice president, membership in the Essex (County, N. J.) Electrical League, State of New Jersey Emergency Relief Administration, U.S. Chamber of Commerce, The American Society of Mechanical Engineers, and the American Transit Association. During the World War he served on important committees of the U.S. Army and Navy. His numerous contributions to the technical press have dealt chiefly with electric transmission and distribution problems and include his book, "Underground Transmission and Distribution."

Vice Presidential Nominees Are Christie, Eldredge, Fair, Harrison, Hinson

Clarence Victor Christie (A'08, M'13, F'32) professor of electrical engineering and chairman of the department of electrical engineering, McGill University, Montreal, Canada, has been nominated to serve the Institute as vice president representing the Canadian District (number 10). He was born at Couva, Trinidad, British West Indies, February 2, 1882. He received the degree of bachelor of arts in 1902, and that of master of arts in 1903 from Dalhousie University, Halifax, Nova Scotia, and that of bachelor of science in electrical engineering from McGill University in 1906. After graduation he spent one year 1906–07 on the apprenticeship course of Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., returning to McGill University as lecturer in electrical engineering in 1907. He was appointed assistant professor in 1908, associate professor in 1915, and since 1926 has been professor of electrical engineering and chairman of the department. In 1918 he became associated with the Shawinigan Water and Power Company as consulting engineer and has thus been able to keep in close touch with the practical side of the profession of electrical engineering. In addition to his duties with this company, he has made studies and reports on important transmission projects as well as appraisals of large electrical utility properties. He has served the Institute for several years as a member of the transmission and distribution committee, 1928–29, 1930–35; and as a member of the committee on education, 1927–28. He was recently appointed a member of the transmission and distribution committee of the Edison Electric Institute. Since 1926 he has been chairman of the electrical sectional committee of the Canadian Engineering Standards Association, and as their representative was appointed a member of the sectional committee on electrical definitions, and is acting as chairman of subcommittee 2*A* engaged in preparing definitions on rotating machinery. Since 1928 he has been chairman of the engineering section of the Canadian Electrical Association; he also is a member of the Engineering Institute of Canada, for which he has served as a member of its council, 1931–32. His textbook "Electrical Engineering," first published in 1913, is now in its fourth edition and has been widely used both in Canada and the United States.

Mark Eldredge (A'14, M'20, F'33) chief engineer, Memphis Power and Light Company, Memphis, Tenn., has been nominated to serve the Institute as vice president representing the Southern District (number 4). He was born at Woodbury, N. J., May 17, 1882. After attending public schools he learned the trades of electrician and lineman, and in 1906 graduated from Worcester Polytechnic Institute, with the degree of bachelor of science in electrical engineering. During the year 1906–07 he was on the graduate student engineer course of the General Electric Company of Schenectady, N. Y.; and the next 2 years, 1907–09, he was engaged on North Dakota pumping projects of the U.S. Reclamation Service. During 1909–11 he was superintendent of power for the Gilson Asphaltum Company, Dragon, Utah, and superintendent for the Rocky Mountain Manufacturing Company, Colorado Springs. He then became professor of electrical engineering at Ewing College, Allahabad, India; and in 1913 became electrical assistant to the textile engineer of the Tata

Hydro-Electric Power Supply Company, Bombay. During 1915–18 he was distribution engineer of the same company. He was a captain, construction division, quartermaster corps, U.S. Army, on the staff of the constructing quartermaster, Erie Proving Grounds, Ohio, 1918–19. From 1919 to 1922 he was superintendent of power for the Ludlow Jute Company, Calcutta, India, building a jute textile mill with complete electric drive, and employees' town with all utility services, and a modern high efficiency generating station. From 1922 to 1924 he was assistant engineer of the Electric Bond and Share Company, New York, N. Y., and since 1924 has been chief engineer of the Memphis Power and Light Company. Mr. Eldredge organized and was first chairman of the Memphis Section of the A.I.E.E., and is serving the Institute as a member of the committee on power transmission and distribution, 1933–35, and Sections committee, 1934–35. He also has been active on the committees of the former National Electric Light Association, and was vice chairman of its engineering national section, 1930–33. He is now chairman of the transmission and distribution committee of the Edison Electric Institute. Mr. Eldredge is president of the Engineers' Club of Memphis.

Richard Harvey Fair (A'09, M'20) plant operations supervisor of the Northwestern Bell Telephone Company, Omaha, Neb., has been nominated to serve the Institute as vice president representing the North Central District (number 6). He was born on a farm in Dakota County, Neb., December 16, 1872. After graduating from Midland Academy, he completed his sophomore year in the classical course at Midland College, and afterward studied electrical engineering for 2 years at the University of Nebraska. He entered the employ of the Nebraska Telephone Company (Bell) in 1896, and has been continuously in the employ of that company and its successors since that time. Since 1909 he has been in the employ of the Northwestern Bell Telephone Company, covering the states of Minnesota, Iowa, Nebraska, South Dakota, and North Dakota. During these periods, he was in construction and engineering work for 12 years, including 2 years as superintendent of construction; then outside plant engineer for 12 years; general superintendent of plant for 8 years; and, since 1928, plant operations supervisor of the Northwestern Bell Telephone Company. His responsibilities when outside plant engineer also included transmission engineering, valuation and rate case work, and relations with power and electric light companies on all phases of outside plant standards. During this service as outside plant engineer, he collaborated with other engineers in the Bell system in developing outside plant standards. As general superintendent of plant he had responsibility for the field engineering and construction of all outside plant and station equipment, and for the maintenance of the entire plant. As plant operations supervisor, he acts in a consulting capacity to the 4 area operating organizations and acts in a coördinating capacity between these organizations. Since 1923 he has taken a leading part in the management group dealing with employee relations.

William Henry Harrison (A'20, M'30, F'31) operating vice president of the Bell Telephone Company of Pennsylvania and the Diamond State Telephone Company of Delaware, with headquarters in Philadelphia, Pa., has been nominated to serve the Institute as vice president, representing the Middle Eastern District (number 2). He was born in Brooklyn, N. Y., June 11, 1892. He graduated from the electrical engineering course of Pratt Institute, Brooklyn, and in 1909 joined the New York Telephone Company in New York City, as repairman. His work until 1915 included apparatus inspection, assembling, and wiring. Between 1915 and 1919 he was engaged in telephone circuit design with the Western Electric Company, in its engineering department. Between 1919 and 1924 he was engaged in general plant maintenance engineering as a member of the engineering staff of the American Telephone and Telegraph Company. In 1924 he was made equipment and building engineer of the American Telephone and Telegraph Company, with general supervision of the engineering and design, including layout, of subscribers' station and central office plant of the Bell system. In 1929 he became plant engineer, this appointment giving him general supervision of the engineering, design, and layout of all parts of the Bell system plant including system relations with other wire-using utilities. In 1933, he was appointed to his present position of operating vice president of the Bell Telephone Company of Pennsylvania, and the Diamond State Telephone Company of Delaware. Mr. Harrison has been active for several years on the committees of the Institute, having been a member of the following committees: technical program, 1929–35 (chairman, 1931–33); coordination of Institute activities, 1931–33; publication, 1931–33; award of Institute prizes, 1931–34 (chairman, 1931–33); Popular Science Award, 1931–34; legislation affecting the engineering profession, 1932–35; and special committee on Associate dues and related matters, 1932–35. He also has served as a representative of the Institute on the Alfred Nobel prize committee of the American Society of Civil Engineers, 1932–34; and on the American committee on marking of obstructions to air navigation, 1932–33.

Noel Bertram Hinson (A'19, M'26) chief engineer and chairman of the engineering committee for the Southern California Edison Company, Ltd., Los Angeles, has been nominated to serve the Institute as vice president representing the Pacific District (number 8). He was born December 25, 1885, at Evansville, Ind. In 1906 he joined the organization of the former Edison Electric Company, a predecessor of the Southern California Edison Company; here he remained in the test department until 1912 when he was transferred to the distribution department in the general offices. In 1913 he was appointed to the position of distribution engineer in charge of the general layout of distribution lines over the entire system. He was made assistant superintendent of distribution of the Southern California Edison Company, in 1920, the name having been changed in 1915. In 1923 he was appointed system planning engineer and chairman of the planning committee, and as such had general supervision over the location and general design of the major portion of the transmission system, substation, and main distribution feeders of the Edison company system as it exists today. In 1928, he was given the position of assistant manager of operation, still remaining chairman of the planning committee. The operating department operates and maintains the generating plants, substations, and transmission and distribution lines, and constructs all distribution lines and most of the transmission lines. In 1934 he was made chief engineer of the company and chairman of the engineering committee. Mr. Hinson is a past chairman of the Institute's Los Angeles Section, and is the author of a large number of technical papers on the operation and construction of various features of power systems.

Jones, Kouwenhoven, Shaad Nominated for Institute Directorships

Charles Ramey Jones (A'16, M'30) eastern transportation manager, Westinghouse Electric and Manufacturing Company, New York, N. Y., has been nominated to serve the Institute as a member of its board of directors. He was born at Norristown, Pa., May 11, 1886. In 1907, he graduated from the University of Pennsylvania, with the degree of bachelor of science in electrical engineering. Since 1907 he has been continuously with the Westinghouse Electric and Manufacturing Company. For the first 2 years, until 1909, he was on the engineering apprentice course of the company at East Pittsburgh, specializing in railway work. For the next 2 years, until 1911, he was in the engineering and railway department of the company, also at East Pittsburgh, being transferred in the latter year to the New York office where he was assistant to the manager of the railway division until 1916. From 1916 to 1925 he was sales engineer in the New York office of the Westinghouse company, representing the company on large contracts involving both engineering and commercial phases. This included work in connection with the electrification of steam railroads and power supply and car equipment for the local rapid transit company. From 1925 to 1930, he was section manager of the transportation division of the New York office, continuing the same work, but in a supervisory capacity. In the latter year he became assistant northeastern transportation manager, and in 1931 transportation manager of what is now the eastern district. Mr. Jones has served the Institute as a member of the national membership committee, 1928–31, and has engaged for a number of years in the activities of the New York City District (number 3), having been District secretary

1930–35. He also has served the Institute's New York Section as secretary, 1930–31; chairman, 1933–34; and as chairman of the transportation group and as a member of program committees. He has been active for several years in connection with the Institute's winter convention, having served as a member of convention executive committees, and being at present chairman of the general committee for the 1935 winter convention. He is a member of the New York Electrical Society, Propeller Club (national marine organization), New York Railroad Club, New York Engineers' Club, Hackensack (N. J.) Golf Club, and Sigma Alpha Epsilon fraternity.

William Bennett Kouwenhoven (A'06, M'22, F'34 and past vice president) professor of electrical engineering and assistant dean, The Johns Hopkins University, Baltimore, Md., has been nominated to serve the Institute as a member of its board of directors. He was born January 13, 1886, at Brooklyn, N. Y. From Brooklyn Polytechnic Institute, he received the degree of electrical engineer *cum laude* in 1906, and that of mechanical engineer *summa cum laude* in 1907. From the Karlsruhe Technische Hochschule, Baden, Germany, he received the diploma in engineering *summa cum laude* in 1913, and the degree of doctor of engineering *magna cum laude* in 1914. During 1906–07 he served as assistant in physics at Brooklyn Polytechnic Institute, and during 1907–10 was instructor in physics and electrical engineering at the same institution. During 1913–14 he was instructor in electrical engineering at Washington University, St. Louis, Mo. In 1914 he joined the staff at The Johns Hopkins University. Here he was instructor in electrical engineering, 1914–17, and associate in electrical engineering, 1917–19. After a leave of absence, 1919–20, he was engineering superintendent at the Winchester Repeating Arms Company, New Haven, Conn., and in 1919 returned to The Johns Hopkins University as associate professor in electrical engineering. He held this position until 1930 when he received his present appointment as professor of electrical engineering and assistant dean. Professor Kouwenhoven acted as instructor in the Reserve Officers Training Corps unit and held the rank of captain during the war. He has served part-time acting as a consulting electrical engineer at the U.S. Bureau of Standards. Professor Kouwenhoven served the Institute as a vice president 1930–33, and has been a member of the following Institute committees: coordination of Institute activities, 1927–30; Sections, 1925–34 (chairman, 1927–30); technical program, 1931–35; safety codes, 1933–35; electrophysics, 1924–33; instruments and measurements, 1925–35 (chairman, 1933–35); research, 1933–35; and telegraphy and telephony (now communication) 1919–20. He now represents the Institute on the sectional committee on electrical insulating materials of the American Standards Association. He also has been active in the Institute's Baltimore Section, having served as chairman and in other capacities. Professor Kouwenhoven has published a very large number of papers and articles on his research work, including, most recently, the subjects of instruments and measurements, and the effects of electric shock. Professor Kouwenhoven has been active in the American Society for Testing Materials, and is a member of The Johns Hopkins Club and the Baltimore Engineers' Club. In 1932 he was awarded special honor by those in charge of the International Electrical Congress held in Paris, July 4–12, 1932.

George Carl Shaad (A'03, M'08, F'13, and past vice president) dean, school of engineering and architecture, University of Kansas, Lawrence, has been nominated to serve the Institute as a member of its board of directors. He was born in Stratford, N. Y., May 5, 1878. He graduated from Pennsylvania State College in 1900 with the degree of bachelor of science in electrical engineering, and in 1905 received the degree of electrical engineer from the same institution. On graduation he entered the testing department of the General Electric Company at Schenectady, N. Y., and in 1902 transferred to the switchboard engineering department. In the latter year he was appointed instructor in electrical engineering at the University of Wisconsin. In 1904 he became assistant professor of electrical engineering at that institution. In 1906 he transferred to the Massachusetts Institute of Technology, where he was assistant professor of electrical engineering. In 1907 he was made an associate professor at M.I.T. When the electrical work at the University of Kansas was separated from the department of physics in 1909, he accepted the appointment as professor of electrical engineering in charge of the department of that institution, and has retained his connection with the University of Kansas since that date. He acted as dean of the school of engineering and architecture and was in charge of the work of the student army training corps in 1917–18. Since 1927 he has held the position of dean of the school of engineering and architecture at the University. He has been employed in engineering work along with his teaching duties and acts in a consulting capacity in connection with various engineering problems. He has been interested in the work of the student Branches of the Institute, and served several years as student Branch counselor delegate for the District. He has also served as chairman of the Kansas City Section. Professor Shaad, in addition to being a member of local engineering organizations, is a member of The American Society of Mechanical Engineers and the Society for the Promotion of Engineering Education, of which he is now a vice president.

W. I. Slichter Renominated as Institute Treasurer

Walter Irvine Slichter (A'00, M'03, F'12, past vice president, and national treasurer) professor of electrical engineering at Columbia University, New York, N. Y., has been nominated to succeed himself as treasurer of the Institute. He was born in St. Paul, Minn., May 7, 1873, and graduated from Columbia University in 1896 with the degree of electrical engineer. Since 1914 Professor Slichter has been an active member of 18 Institute committees and has represented the Institute on 6 joint bodies; he is now a member of 7 committees and a representative on 4 bodies. A full biographical sketch of Professor Slichter's career was published on page 56 of Electrical Engineering for January 1931.

Willis R. Whitney to Receive Edison Medal

Willis Rodney Whitney (A'01) vice president in charge of research for the General Electric Company, Schenectady, N. Y., has been awarded the A.I.E.E. Edison Medal for 1934 "for his contributions to electrical science, his pioneer inventions, and his inspiring leadership in research." Actual presentation of the

WILLIS R. WHITNEY

medal will take place during the forthcoming A.I.E.E. winter convention to be held in New York, N. Y., January 22–25, 1935. The Edison Medal was founded by friends and associates of the late Thomas A. Edison (A'84, M'84, HM'28, and member for life) and is awarded annually for "meritorious achievement in electrical science, electrical engineering, or the electrical arts," by a committee consisting of 24 members of the Institute. Doctor Whitney, the 24th recipient of this medal, was born at Jamestown, N. Y., August 22, 1868. He graduated from the Massachusetts Institute of Technology, Cambridge, with the degree of bachelor of science in 1890, and in 1896 received the degree of doctor of philosophy from Leipsig University. Honorary degrees have since been conferred upon him by 6 universities. Since his graduation from Massachusetts Institute of Technology, he has held the following positions at that institution: assistant instructor in general chemistry 1890–92, analytical chemistry 1892–94, sanitary chemistry 1896–98, instructor in theoretical chemistry and proximate analysis 1898–01, assistant professor of theoretical chemistry 1901–04, nonresident associate professor of theoretical chemistry 1904–08, and nonresident professor of chemical research since 1908. Doctor Whitney assumed the directorship of the

research laboratory of the General Electric Company at Schenectady upon its establishment in 1900. The expansion of the laboratory followed the development by Doctor Whitney of a new type of incandescent electric lamp, and since 1903 the laboratory has grown rapidly. In 1928, Doctor Whitney became vice president of the company, and director of research. In 1932 he retired from active direction of the laboratory due to ill health, and was made vice president in general charge of research, which position he has since held. Although Doctor Whitney's greatest personal activity has been in the field of chemistry, he has, through the laboratory, been active in many researches which have made outstanding contributions to the electrical industry. He also has contributed frequently to technical literature, having published more than 80 papers. Among the many honors which Doctor Whitney has received are the Willard Gibbs Medal, 1916; Chandler Medal, 1920; Perkin Medal, 1921; the gold medal of the National Institute of Social Sciences, 1928; and the Franklin Medal, 1931. Doctor Whitney is a member of the American Chemical Society (president 1909), American Society of Chemical Engineers, American Electrochemical Society (president 1912), American Institute of Mining and Metallurgical Engineers, American Physical Society, American Association for the Advancement of Science, American Philosophical Society, American Academy of Arts and Sciences, National Academy of Sciences, National Research Council, and the British Institute of Metals. He is also a member of the U. S. Naval Consulting Board, and is an honorary member of the American Society of Steel Treaters. Doctor Whitney is a member of the board of governors of Union University, a trustee of Union College and of the Albany Medical College, and was a term member of the corporation of the Massachusetts Institute of Technology, 1917–21, 1923–28.

F. B. Jewett (A'03, M'10, F'12, and past president) vice president of the American Telephone and Telegraph Company, and president of the Bell Telephone Laboratories, Inc., has been elected to honorary membership in the Institute of Electrical Engineers of Japan (the "Denki-Gakkwai"). Doctor Jewett was born in Pasadena, Calif., Sept. 5, 1879, and in 1898 graduated from Throop Polytechnic Institute (now the California Institute of Technology) at Pasadena, with the degree of bachelor of arts. He then took up graduate work at the University of Chicago under Prof. A. A. Michelson, receiving the degree of doctor of philosophy in 1902. After serving one year as an assistant to Professor Michelson, he became instructor in physics and electrical engineering at Massachusetts Institute of Technology, and in 1904 joined the staff of the American Telephone and Telegraph Company. In 1912 he became assistant chief engineer of the Western Electric Company, in 1916 chief engineer, and in 1921 vice president of the company. At the beginning of 1925 he became vice president of the American Telephone and Telegraph Company, and at the same time was made president of the Bell Telephone Laboratories, Inc., which positions he has since held. Doctor Jewett has served the Institute as manager, 1915–18; vice president, 1918–19; and president 1922–23. He also has served on some 16 of the Institute's committees and as its representative on 8

F. B. JEWETT

other bodies. He has presented many papers and articles before the Institute and other organizations, and has been active in The Engineering Foundation and National Research Council. Since the formation of the Institute's committee for the Iwadare Foundation in 1931, Doctor Jewett has been its chairman. This committee selects lecturers sent to Japan under the Iwadare Foundation of the Institute of Electrical Engineers of Japan, and assists students sent to this country from Japan. The Fourth Order of the Rising Sun and the Third Order of the Sacred Treasure have been bestowed upon him by the Japanese government. In 1928, Doctor Jewett was awarded the Edison Medal of the A.I.E.E. He is active on many other bodies, being a term member of the Massachusetts Institute of Technology, a member of the committee on Carnegie Institute of Technology, and a member of the board of trustees of the Carnegie Institution of Washington, D. C.

H. P. Charlesworth (M'22, F'28, and junior past-president) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y., was recently elected chairman of the board of the Engineering Foundation and representative on the National Research Council to fill unexpired terms ending on February 21, 1935. Mr. Charlesworth has been active in Institute committee work, and is now chairman of the committee on Institute policy and a member of the Edison medal and code of principles of professional conduct committees, and a representative of the Institute on the John Fritz medal board of award. He was a manager 1923–27, vice president 1930–32, and president 1932–33.

C. V. Woolsey (M'22) for several years system engineer, Brooklyn Edison Company, Brooklyn, N. Y , has been appointed director of the inventory, heading the newly created department of the inventory. The function of the department is to provide a continuing record of all future additions and withdrawals of property. Since joining the company in 1909 Mr. Woolsey has been draftsman, assistant to the electrical engineer, electrical system engineer, and system engineer. He was a member of the Institute's membership committee 1926–7.

F. A. Gaby (A'06, F'18) formerly chief engineer, Hydro-Electric Power Commission of Ontario, Toronto, Can., has been appointed assistant to the president of the Canadian Pacific Railway, with headquarters at Montreal. He had joined the commission in 1907, and had been chief engineer since 1912. In his new position he will have charge of the investigation of the forms of competition, and company policies in regard to them. Mr. Gaby has been a member of the Institute's Edison medal committee since 1930.

J. S. Mahan (A'12, F'27) fire prevention and electrical engineer, Oak Park, Ill., has been employed by the Edison Electric Institute to present the views of the electric utilities on national electrical code questions. He was formerly an electrical inspector connected with the Western Actuarial Bureau and for many years was a member of the electrical committee of the National Fire Protection Association. More recently he has been connected with various manufacturers of electrical wiring materials.

H. S. Broadbent (A'22) formerly manager, commercial engineering department, Westinghouse Lamp Company, Bloomfield, N. J., has been appointed assistant to the vice president of the company. Mr. Broadbent graduated from Cornell University in 1917 and joined the Westinghouse organization in 1921 as a lamp development engineer, later transferring to the commercial engineering department. He has served on the Institute's committee on the production and application of light since 1929.

D. W. Atwater (A'34) has been appointed manager of the commercial engineering department of the Westinghouse Lamp Company, Bloomfield, N. J. He is a graduate of Stevens Institute of Technology, and has been with the Westinghouse organization about 15 years. Among the lighting installations on which he coöperated were the Holland Tunnel, New York, N. Y., and the Century of Progress, Chicago, Ill.

R. A. Hopkins (M'19) formerly a member of the consulting engineering firm of Hopkins and Gove, Waltham, Mass., has been appointed engineer in charge of hydroelectric station design for the Tennessee Valley Authority, Knoxville, Tenn. Mr. Hopkins was with Stone and Webster Engineering Corporation, Boston, Mass., for 22 years and has been in charge of a number of electrical project developments.

Wilfred Sykes (A'09, F'14) assistant to president, Inland Steel Company, Chicago, Ill., has been nominated as a director of the American Institute of Mining and Metallurgical Engineers. Mr. Sykes has served on a number of A.I.E.E. committees, most recently as a member of the committee on

applications to iron and steel production, and was a manager of the Institute 1917–21.

J. B. Cox (A'09) recently retired electrical engineer of the transportation department, General Electric Company, Erie, Pa., now resides at Knoxville, Tenn. He had charge of the company's interests in many railroad electrification projects in this country and abroad, including the Chicago, Milwaukee, St. Paul and Pacific; Great Northern Railway; and the Mexican Railway.

G. E. Castellan (A'30) formerly engineering estimator with the General Electric Company, Ltd., Birmingham, England, is now with Clements and Son, London, where he will assist in technical matters. He recently received a diploma in electrical engineering from University College, London, and is a member of the Institution of Electrical Engineers.

G. N. Brown (A'13, M'21) manager of the electric refrigeration bureau, Edison Electric Institute, New York, N. Y., for the past 3 years, has been appointed a special utilities sales representative for Kelvinator Corporation, with headquarters in New York. Mr. Brown has previously been connected with the Ohio Insulator Company and the Pittsburgh Transformer Company.

E. E. Johnson (A'25), since 1931 assistant executive engineer, research laboratory, General Electric Company, Schenectady, N. Y., has been appointed engineer of the generator voltage regulator department. Mr. Johnson is a graduate of Washington State College and has been with the company since 1922.

H. J. Reeves (A'30) since 1929 junior engineer, New York and Queens Electric Light and Power Company, Flushing, N. Y., has formed the partnership of Paul and Reeves, manufacturing agents, Spokane, Wash. He has served on several New York Section committees.

T. H. Hogg (M'31) chief hydraulic engineer, Ontario Hydro-Electric Power Commission, Toronto, Can., has been appointed a member of the main committee of the Canadian Engineering Standards Association. Dr. Hogg has been a member of the Institute's standards committee since 1932.

S. A. Staege (A'10, F'19) formerly a consulting engineer with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., is now a consultant for Black-Clawson Company, Hamilton, Ohio, and Shartle Brothers Machine Company division at Middletown, Ohio.

H. J. Gille (A'01, M'13) manager, agricultural and industrial development, Puget Sound Light and Power Company, Seattle, Wash., has been named as one of a committee of 12 to study the creation of a new state bureau for promoting new settlers in the state of Washington.

Paul Ransom (A'21, M'31) formerly electrical engineer, Utah Apex Mining Company, Bingham Canyon, Utah, has accepted a position as electrical engineer for the Mountain Copper Company, Ltd., Shingle Springs, Calif.

R. R. Law (A'31) of Cicero, Ill., formerly a research assistant in geophysics at Harvard University, Cambridge, Mass., is now an electrical engineer in the research and development laboratory of the R.C.A. Radiotron Company, Harrison, N. J.

I. F. McIlhenny (A'25) assistant professor of electrical engineering, Fenn College, Cleveland, Ohio, is on leave of absence and is engaged on the construction of the Madden dam and power station for the Panama Canal.

E. W. Fisher (A'33) until recently power plant cadet engineer, Kansas City Power and Light Company, Tecumseh, Kan., is now engineering and technical advisor, public service commission of Kansas, Topeka.

H. W. Graybrook (A'26) New Albany, Ind., has become chief engineer for the Clements Manufacturing Company, Chicago, Ill. He was previously chief engineer for the Marathon Electric Manufacturing Corporation, Wausau, Wis.

H. R. Stewart (A'26) formerly general engineer, Westinghouse Electric and Manufacturing Company, Boston, Mass., has joined the New England Power Engineering and Service Corporation as protection engineer.

D. L. Bement (A'25) formerly technical assistant, Northern Indiana Public Service Company, Hammond, has been named general superintendent in charge of production transmission, and distribution for the entire system.

Russell Ranson (A'33) who was employed in the radio consulting department, General Electric Company, Schenectady, N. Y., has become an instructor in electrical engineering at Duke University, Durham, N. C.

H. K. Ansingh (M'22) former manager, Canadian Crocker Wheeler Co., Ltd., St. Catherines, Ont., Can., has become vice president and managing director of the Commonwealth Electric Corporation, Welland, Ont.

J. B. MacLean (A'27, M'30) formerly assistant engineer, Central Railroad Company of New Jersey, Jersey City, is now with the Riegel Paper Corporation, New York, N. Y.

W. S. McCrea, Jr. (A'26) formerly with the department of public works, state of Washington, Olympia, is now rate engineer, department of public utilities, city of Tacoma.

J. F. Imle (A'32) geophysical engineer formerly with the Standard Oil Company of Venezuela, Marcaibo, is now employed by the Humble Oil and Refining Company, Houston, Tex.

A. C. Alizo (A'32) has resigned as manager and engineer, Cia. Annma. Planta Electrica de Valera, Venezuela, and has engaged in private work as a consulting engineer at Escuque, Trujillo, Venezuela.

G. A. Anderson (A'31) formerly assistant to regional construction manager, Montgomery Ward and Company, Oakland, Calif., has become assistant construction superintendent.

J. R. C. Armstrong (A'02, F'13) who recently became engineer examiner for the Federal Emergency Administration of Public Works, has been transferred from Washington, D. C., to Fort Worth, Texas.

W. C. Cram, Jr. (A'14) formerly Georgia district manager, Allied Engineers, Inc., Atlanta, is now technical assistant to the assistant secretary of the treasury, Washington, D. C.

F. R. Phillips (M'27) president, Philadelphia Company, Pittsburgh, Pa., was elected president of the American Transit Association at the recent annual convention held in Cleveland, Ohio.

G. H. Bucher (M'24) president, Westinghouse Electric International Company, New York, N. Y., has been elected a director of the American Manufacturers Export Association.

A. J. Althouse (A'11, M'29) assistant general manager, Metropolitan Edison Company, Reading, Pa., was recently elected a vice president of the Pennsylvania Electric Association.

L. A. Ferguson, Jr. (A'28) formerly construction engineer, Commonwealth Edison Company, Chicago, Ill., has been appointed to the newly created position of assistant general service manager.

D. E. Batchelder (A'28) research assistant, Pasadena Water Department, has been transferred from Azusa, Calif., to Pasadena. He is working on measurements on the Morris Dam.

M. N. Larson (A'28) assistant system operator, Public Service Company of Northern Illinois, has been transferred from Wheaton to Evanston.

J. A. Smith (A'31) electrical engineer, Associated General Electric Industries, Ltd., has been transferred from Perth, Australia, to Tasmania.

J. E. Vipond (A'23) has recently become electrical designer and draftsman for W. G. Chace, consulting engineer, Toronto, Ont., Canada.

C. E. O'DONNELL (A'32) of Champaign, Ill., has recently entered the distribution department of the Central Illinois Public Service Company, Maltoon.

F. E. CHESTER (M'28) ship designer formerly with the Electric Boat Company, Groton, Conn., is now with the United Dry Docks Company, New York, N. Y.

I. L. CRAIG (A'09) rate engineer, Philadelphia Electric Company, Philadelphia, Pa., was recently elected a vice president of the Pennsylvania Electric Association.

C. K. BEYETTE (A'34) is a student engineer employed by the Texas Electric Service Company, Eastland.

D. H. SMITH (A'32) of St. Elmo, Ill., is now employed by the Illinois Testing Laboratories, Inc., Chicago.

E. T. LENTZ (A'33) until recently a repairman, Ohio Bell Telephone Company, Toledo, is now a draftsman for the company.

L. W. HENRY (A'16) electrical engineer, Aluminium, Ltd., has been transferred from New York, N. Y., to Montreal, Que., Can.

Obituary

GEORGE FITCH BROWN (M'18) manager generator and converter division, central station department, General Electric Company, Schenectady, N. Y., died November 26, 1934. He was born at Geneva, Neb., May 2, 1880. In 1904 he graduated from the University of Nebraska with the degree of bachelor of science in electrical engineering and, until he entered the General Electric Company in 1905, worked as an estimator for an electrical contractor. He became a designing engineer in the a-c department in 1907, and remained in this work until 1915, when he became an engineer with the Southwark Foundry and Machine Company, Philadelphia, Pa. Two years later he returned to the General Electric Company as an engineer in the central station engineering department, and was placed in charge of the apparatus section in 1928. He became manager of the generator and converter division when it was formed in 1933.

CHRISTOPHER MARSH GODDARD (A'96, M'02) chairman committee on public relations, New England Insurance Exchange, Boston, Mass., died Nov. 12, 1934, at his home in Summit, N. J. He was born at Claremont, N. H., April 16, 1856. In 1877 he received the degree of bachelor of science from the Chandler school of science, Dartmouth College, and for the following 3 years was instructor in higher mathematics at Cheshire (Conn.) Academy. During the next 10 years he was employed successively in a banking firm, a telegraph company, and in electric lighting construction, accepting an appointment as electrical inspector for the New England Insurance Exchange in 1890. The following year he became secretary and consulting electrician. At this time he formulated the requirements for construction and equipment of electric light and power stations, and in 1892 suggested and organized the Underwriter's National Electric Association, which had charge of formulating the national electrical code. He became a member of the National Fire Protection Association at the time of its formation, and is credited with originating in 1892 a publicity campaign for a national fire prevention week. At one time he served as president of the association. Mr. Goddard was the author of a number of articles on the fire hazard of electricity, and was the chairman of a special committee appointed at the request of the A.I.E.E. to consider the subject of the grounding of low potential circuits. He resigned as secretary of the insurance exchange in 1925.

HERSCHEL HUGH EDWARDS (A'31) assistant to transmission engineer, New York Telephone Company, Mt. Vernon, N. Y., died in June 1934, according to word just received at Institute headquarters. He was born at Indianapolis, Inc., May 4, 1906. After graduating from Balboa high school, Canal Zone, in 1923, he was employed by the Bell Telephone Company there for 2 years, after which he was employed for short periods by the Christophers Ice Cream Company, Los Angeles, Calif., and the Luxortone Talking Picture Corporation. In 1928 he became transmission engineer's assistant with the New York Telephone Company.

JAMES F. SINCLAIR (A'27) general manager, Jeffery-Dewitt Insulator Company, Kenova, W. Va., died October 23, 1934. He was born at Sarnia, Ont., Can., April 17, 1877. In 1922 he assumed the office of general manager of the insulator company, and the following year became also general manager and treasurer of the Champion Switch Company, Buffalo, N. Y. During the past 2 years he had been in poor health and had delegated most of his duties to others.

FRANK O'RYAN (A'16) Denver, Colo., district manager Allis-Chalmers Manufacturing Company, died November 23, 1934. He was born in 1881, and received his early electrical experience as a testing and installation engineer with the General Electric Company at Fort Wayne, Ind. He went to Denver in 1910 to enter the sales office of the Allis-Chalmers Company, and became manager in 1919. Mr. O'Ryan was also a member of the Rocky Mountain Coal Mining Institute.

T. J. DRURY (A'25) teacher, board of education, New York, N. Y., died August 3, 1934. He was born at Roscommon, Ireland, November 20, 1885, and was a graduate of Cooper Union, New York, N. Y. For a short time in 1918 he was employed by the Western Electric Company as an inspector, and had similar duties for the war department in 1918. More recently he had been employed by the Star Publishing Company, New York, N. Y.

CHARLES ELLISON HENDRICKS (A'27) General Electric Company, Chicago, Ill., was killed in a motor accident on June 29, 1934. He was born at Douglas, Ga., July 4, 1904, and received the degree of bachelor of science from Georgia Institute of Technology. For a short time in 1925 he was employed by the Georgia Railway and Power Company, entering the General Electric Company later in that year.

Membership

Recommended for Transfer

The board of examiners, at its meeting of December 19, 1934, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Culver, L. R., assoc. prof. of elec. engg., Univ. of Cincinnati, Cincinnati, Ohio.

1 to Grade of Fellow

To Grade of Member

Bartholomew, Francis J., president and general manager, Electric Power Equipment Ltd., Vancouver, B. C.
Bell, Edgar, test engr., Penn. Pwr. & Lt. Co., Hazleton, Pa.
Cole, Clarence S., engr., Peter F. Loftus, consulting engineers, Pittsburgh, Pa.
Eaton, James R., transmission line engg., Consumers Pwr. Co., Jackson, Mich.
Kvamme, Ingolf, division engr., Duquesne Lt. Co., Beaver Falls, Pa.
Maxwell, Howard, mgr., design and manufacture, induction motors, Gen. Elec. Co., Schenectady, N. Y.
Ransdall, Ralph A., asst. engr. of line constr., Pacific Gas & Elec. Co., San Francisco, Calif.
Webb, Roy L., asst. engr., Brooklyn Edison Co. Inc., Brooklyn, N. Y.

8 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Jan. 31, 1935, or March 31, 1935, if the applicant resides outside of the United States or Canada.

Baker, R. V., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
Bangs, G. L., Rochester Gas & Elec. Corp., Rochester, N. Y.
Bartley, J. L., Cleveland Securities Corp., Cleveland, Ohio.
Benson, J. P., 1186 Washington Ave., Bronx, N. Y.
Blair, W. H., Potomac Elec. Pwr. Co., Washington, D. C.
Bloomberg, J. B., Southwestern Bell Tel. Co., St. Louis, Mo.
Bryan, P. D., N. Y. Tel. Co., Albany.
Campbell, J. H., Gen. Elec. Co., Cleveland, O.
Cary, A. R., Buffalo Steel Co., Tonawanda, N. Y.
Chase, C. W., Indianapolis Ry., Indianapolis, Ind.
Dalton, W. J., Brooklyn Edison Co., Inc., Bklyn., N. Y.
Davis, W. C., Fenn College, Cleveland, Ohio.

Diestler, E. A., 125 Salisbury St., Worcester, Mass.
Fisher, D., American Tel. & Tel. Co., N. Y. City.
Fountain, J. B., Mississippi Pwr. & Lt. Co., Greenville.
Fryer, J. C., Schweitzer & Conrad Inc., Chicago, Ill.
Gilliland, C. W., General Cable Corp., Emeryville, Calif.
Graham, A. L., Eastern Pwr. Devices, Ltd., Toronto, Ont., Can.
Helldoerfer, C. J., Dayton Pwr. & Lt. Co., Dayton, Ohio.
Honig, A. R., Jr., Gen. Elec. Co., Jackson, Mich.
Horsley, C. B. (Member), Waite & Bartlett X-Ray Mfg. Co., Cleveland, O.
Kaleda, G. M., Philadelphia & Reading Coal & Iron Co., Mahanoy City, Pa.
King, R., 2601 Kingsland Ave., Oakland, Calif.
Kopas, J. S., Fenn College, Cleveland, Ohio.
Kruszka, J. F. (Member), Jensen, Bowen & Farrell, Newark, N. J.
Lawrence, G. R., 14 Ivy St., Boston, Mass.
Logan, F. G., Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Lorenz, R. D., El Paso Elec. Co., El Paso, Tex.
Nimmo, J. M., Jr., Virginia Elec. & Pwr. Co., Norfolk.
Nisula, C. W., U. S. Navy, Rm. 629, Federal Bldg., Detroit, Mich.
Oliver, G. W., Pwr. & Lt. Co., Pine Bluff, Ark.
Otani, M., Internatl. Gen. Elec. Co., Schenectady, N. Y.
Perine, W., N. Y. Edison Co., N. Y. City.
Phillips C. A., Virginia Elec. & Pwr.Co., Richmond.
Plusch, J. O., U. S. Coast Guard "Aurora," San Pedro, Calif.
Porter, J. S., Westinghouse Elec. & Mfg. Co., Oklahoma City, Okla.
Reid, C. A., U. S. Geological Survey, Rolla, Mo.
Reisman, L., 4065 Carpenter Ave., N. Y. City.
Robert, P. A., 312 West 109th St., N. Y. City.
Roper, B. W. A., Penn. P. & L. Co., Hazleton, Pa.
Salembier, A. H., Desurmont Worsted Co., Woonsocket. R. I.
Schumacher, H. A., Bishop Wire & Cable Corp., N. Y. City.
Smith, R., Oklahoma Gas & Elec. Co., Oklahoma City.
Steinhauer, W. H., Toledo Edison Co., Toledo, O.
Strehlow, H. E., Buffalo Steel Co., Tonawanda, N. Y.
Swartz, T. W., Northwestern Elec. Co., Portland, Ore.
Tretton, J. P., Indianapolis Ry., Indianapolis, Ind.
Walters, N. F., Locke Insulator Corp., Baltimore, Md.
Whistler, J. P., Bell Tel. Lab., N. Y. City.
Williams, H. I., Univ. of Vermont, Burlington.

50 Domestic

Chandra, K., United Provinces Hydro Elec. Scheme, Sambhal, Dist. Moradabad, India.
Maine, B. C. (Member), Cerro de Pasco Copper Corp., Cerro de Pasco, Peru, S. A.
Reiner, R. M., Braden Copper Co., Rancagua-Coya, Chile, S. A.

3 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Adams, William C., 801 S. Lynn St., Champaign, Ill.
Babloozian, Levon M., 776 N. Cass St., Milwaukee, Wis.
Demeros, Andrew G., P. O. Box 787, East Pittsburgh, Pa.
Eberhard, Jacob J., 525 Grant St., Santa Clara, Calif.
Fenn, Fred H., 204 Church St., Baton Rouge, La.
Fennis, A. M., 4266 Old Orchard Ave., Montreal, Que., Can.
Fracker, Henry E., Bell Tel. Labs., 463 West St., N. Y. City.
Gould, Albert S., 41 E. 42nd St., N. Y. City.
Hansen, A. Fred, 2065½ W. 30th St., Los Angeles, Calif.
Ince, Frank Edward, 2282 Yale Ave., Maplewood, Mo.
Jordan, Arthur H., 5729 Chester Ave., Philadelphia, Pa.
Lemen, Foster M., 3009 Seward, Omaha, Nebr.
Mendez, 6 Division St., Schenectady, N. Y.
Quinn, Robert P., Ohio Brass Co., Mansfield, Ohio.
Simpson, Sidney, Deputy Loco. Supt., Eastern Bengal R. R., Kanchrapara, Bengal, India.
Skinner, Dean C., 6014 Walnut St., Pittsburgh, Pa.
Taylor, Robert Z., 120 Hudson St., Redwood City, Calif.
Travers, James E., 12 Farwell Blk., Claremont, N. H.
Turnquist, F. A., 4 Birch Road, Wellesley, Mass.
Williams, G. M., 1331 Touhy Ave., Chicago, Ill.

20 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

A.T.M.—Archiv für Technisches Messen. Lieferungen 31–38, January 1934–August 1934. Munich and Berlin, R. Oldenbourg. Illus., 12x8 in., paper, 1.50 rm. each. An application of the loose leaf method to encyclopedia production. The text consists of brief articles upon measuring instruments and methods for all industrial and scientific purposes, hydraulic, acoustical, chemical, and electrical, together with summaries of accepted practice and reports upon research work, new instruments, etc. No. 36 contains an index to the first 36 issues.

CODES, CARTELS, NATIONAL PLANNING, the Road to Economic Stability. By B. Burn in collaboration with S. Flink. N. Y. and Lond., McGraw-Hill Book Co., 1934. 413 p., illus., 9x6 in., cloth, $4.00. The author, who has had long experience in the management of cartels and trade associations in Germany, here discusses the influence of our present codes upon economic stability, the possible ways in which cut-throat competition and overexpansion can be checked, the organization of American business for self-administration, and the compatibility of national planning with American institutions.

DESIGN of ELECTRICAL MACHINERY. By H. Cotton. Lond. and N. Y., Oxford Univ. Press, 1934. 479 p., illus., 10x6 in., cloth, $9.00. This textbook, intended to meet the requirements for the examinations of the Institution of Electrical Engineers, presents the fundamental principles of the design of all classes of electrical machinery, both d-c and a-c. These principles are discussed, and the necessary formulas derived from them where possible.

ELECTRON TUBES in INDUSTRY. By K. Henney. N. Y. and Lond., McGraw-Hill Book Co., 1934. 490 p., illus., 9x6 in., cloth, $5.00. This book aims to describe industrial applications of thermionic and light-sensitive electron tubes, to explain the fundamental principles involved, and to describe rather fully the newer tubes which are not generally known. The work is a useful survey of a new field, which will obviate the necessity of consulting much scattered periodical material.

Die ELEKTRISCHEN MASCHINEN, Bd. 3. Berechnung und Bemessung. By M. Liwschitz. Leipzig u. Berlin, B. G. Teubner, 1934. 409 p., illus., 9x6 in., cloth, 22.50 rm. Preceding volumes have discussed the general principles of electrical machines and their construction and insulation. This final volume is devoted to design, discussing the magnetic circuit, leakage, losses, heating, current diagram of induction machines, transformers, and all types of machines.

ENGINEERING RADIOGRAPHY. By V. E. Pullin. Lond., G. Bell & Sons, Ltd., 1934. 136 p., illus., 11x8 in., cloth, 45 s. This is intended to be a practical guide to the radiologist in interpreting radiographs of forgings, castings, and other engineering structures. A comprehensive collection of radiographs is presented, showing all the chief and most common flaws in castings, accompanied by photographs of sections of the castings which show the actual conditions. The causes of the flaws are explained in terms of common engineering experience.

Die TECHNIK der FERNWIRKANLAGEN. By W. Stäblein. Munich and Berlin, R. Oldenbourg, 1934. 294 p., illus., 10x7 in., cloth, 15 rm. This volume discusses apparatus and methods for the remote operation, supervision, and control of electric stations, gasworks, waterworks, and other plants. The principles involved in the various operations are described, and the problems met are discussed.

TECHNIQUE of MODERN WELDING. By Prof. P. Bardtke; translated from the 2d German edition by H. Kenney. Lond. and Glasgow, Blackie & Son, Ltd., 1933. 299 p., illus., 9x6 in., cloth, 15 s. A survey of welding technique which will be of use to engineers and a manual for the training of welders, discussing welding processes, applications of welding, testing of welds, and gas cutting.

TEXTBOOK on HYDRAULICS. By G. E. Russell. 4 ed. N. Y., Henry Holt & Co., 1934. 447 p., illus., 9x6 in., cloth, $3.90. A presentation of the fundamental principles of hydraulics, intended for students and as a reference book for engineers. The results of recent research work are included, and references to sources are given. This edition has 4 new chapters on hydraulic turbines and pumps and an appendix giving a general treatment of fluid flow in pipes, covering the problems presented by fluids other than water.

WATER POWER ENGINEERING. By H. K. Barrows. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1934. 762 p., illus., 9x6 in., cloth, $6.00. The principles and practice that underly the design of hydroelectric plants are described in a comprehensive way in this textbook, which has been carefully revised to bring it up to date; especially, the section on the cost and value of water power has been largely rewritten.

WORLD POWER CONFERENCE, SECTIONAL MEETING, SCANDINAVIA, TRANSACTIONS 1933, 7 Vols. Stockholm, Svenska Nationalkommitten för Världskraftkonferenser, 1934. (American Committee, World Power Conference, 1419–21 Chrysler Bldg., N. Y.), illus., 10x6 in., 7 vols., 175 Swedish Kroner. v. 1. 763 p., $14. v. 2. 702 p., $14. v. 3. 336 p., $7.25. v. 4. 615 p., $12.75. v. 5. 692 p., $14. v. 6. 781 p., $16. v. 7. 294 p., $5.50 (approximate prices, vary according to exchange). These volumes contain a full report of the papers and discussions before the technical sessions of the conference, of its organization, personnel, official, and social functions, etc. The theme of the conference was the energy problems of large-scale industry. The individual volumes are: 1, general matters, general summaries of all reports, and the index to the transactions; 2, electrical energy; 3, gas, and solid and liquid fuels; 4, power and heat combinations, and steam-heat consuming industries; 5, iron and steel industry, electrical heating, and the transmission and adaptation of motive power for industrial machinery; 6, railways, and urban and suburban traffic; 7, marine transport.

ELECTRICAL MEASUREMENTS in THEORY and APPLICATION. By A. W. Smith, 3 ed. N. Y. and Lond., McGraw-Hill Book Co., 1934. 413 p., illus., 10x6 in., cloth, $3.00. A progressive text for college students which can be used as a laboratory manual, but which also explains fully the principles involved. The electron theory of electrical phenomena is adopted throughout the book and electrical currents are considered as the flow of electrons along the circuit.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

The Electrical Outlook for 1935.—According to a recent statement by Gerard Swope, President, General Electric Co., the volume of electrical manufacturing during 1934 has been more than 30 per cent greater than in 1933. Consumption of electricity throughout the United States has been approximately 7 per cent greater than in 1933 and is almost up to the maximum consumption in the years 1929 and 1930. This increase has been due largely to the increased use of electrical appliances in the home. The electrical manufacturing industry, and industry in general, has felt most seriously the failure of the revival of orders for capital goods, but with the increased use of electricity and consumers' goods in general, capital goods must also increase. For the year 1935, Mr. Swope looks forward to a continued improvement in business.

General Cable Discontinues Coil Winding Service.—According to a recent announcement by the General Cable Corporation, New York City, its coil winding department has been discontinued as of December 31. This change in policy pertains to finished coils alone. The production of magnet wires of all types will be continued.

Aerovox Reduces Interference-Filter Prices.—In keeping with the far-reaching purposes of the interference-prevention campaign launched by the Radio Manufacturers Association during the recent I.R.E. convention at Rochester, N. Y., a marked reduction in list prices of interference filters is announced by the Aerovox Corporation, Brooklyn, N. Y. The reductions on four items are intended to stimulate the greater sale and use of interference-prevention devices so that various localities may enjoy present-day broadcast and short-wave reception to wider advantage.

Multiple-Point Recording in Colors.—Reading of multiple-point instrument records is greatly simplified by a new system of "numerals in colors" introduced by Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia. This marking system can be specified on Micromax strip-chart recorders for 2, 3, 4, or 6 points. With each of the thermocouples, resistance thermometer bulbs or other primary elements identified on the chart by a numeral, and each numeral distinguished from the others by being printed in a contrasting color, reading of records is made easy, errors are avoided, and time is saved. Colors used are black, green, red, violet, yellow, and blue. Full details and a reproduction of an actual chart in all six colors are contained in Circular 314-I.

Large Trolley Equipment Order to Westinghouse.—Amounting to approximately $60,000, the Westinghouse Electric & Mfg. Co. has received a contract from the J. G. Brill Co., for electrical equipment to be installed on 10 street cars ordered by the Capital Transit Co., at Washington, D. C. Quadruple type 50 horsepower motors and variable automatic control features will give these cars schedule performance possibilities excelling any street cars now operating in regular revenue service, according to railway engineers. The cars will have smooth accelerating and braking rates of 4.75 miles per hour per second and a balancing speed of 40 miles per hour. The cars, of the center exit type, will weigh 33,000 pounds and are each 44 feet in length.

U. S. Navy Buys Diesel Submarine Engines.—The U. S. Navy has recently placed orders for 30 large Diesel engines to be installed in 5 new submarines. The total cost of these engines and the electrical equipment they will drive is nearly $4,000,000. Twenty of the engines are large units for propulsion service and 10 smaller units are for auxiliary service, generating electricity for operating all equipment aboard the vessels. Eight of the large engines and 4 auxiliary units are of a type not previously built in this country, according to Fairbanks, Morse & Co., and these opposed-piston Diesel engines are being furnished by this company. This type of engine has two pistons, an upper and lower in each cylinder, each connected to its own crank-shaft, one above and one below. Advantages of this type of engine are improved combustion efficiency and extreme compactness and light weight for the power developed.

Trade Literature

Network Protector.—Bulletin GEA-2017, 8 pp. Describes a new heavy-duty, automatic, a-c network protector for subway and vault service. General Electric Co., Schenectady, N. Y.

Connectors.—Condensed folder catalog, 6 pp. Illustrates a wide variety of connectors covering every cable, wire, tube, or bar size. Burndy Engineering Co., Inc., 305 E. 45th St., New York.

Motor Price Wheel.—An unusual device, consisting of two 8-inch, revolving fiber disks, for quickly determining the frame sizes and list prices of 448 popular sizes and types of electric motors. The Louis Allis Co., Milwaukee, Wis.

Arc Welders.—Bulletin GEA-1440C, 8 pp. Describes the improved Type WD self-stabilized, single-operator arc welder.—Welding Electrodes and Accessories.—Bulletin GEA-1546B, 16 pp. Describes various types of welding electrodes and welding supplies and accessories. General Electric Co., Schenectady, N. Y.

Pole Top Switches.—Bulletin, 16 pp. Describes improved types MB-139, VMB-139, and FMB-139 pole top, group operated, vertical break switches for disconnecting or load break service and for manual or motor operation. Delta-Star Electric Co., 2400 Block-Fulton St., Chicago, Ill.

Capacitors.—Catalog 6-S, 20 pp. Describes ultra-compact dry electrolytics in various voltage ratings, special self-healing type wet electrolytic condensers, auto vibrator and suppressor condensers; and paper, mica, trimmer, etc. condensers. Solar Manufacturing Corp., 599 Broadway, New York.

Mechanical Rubber Goods.—Catalog, 96 pp. Describes hose, belting, packing, and miscellaneous mechanical rubber products. Diagrams illustrate various applications; tables are included with belt speeds, steam pressures and temperatures, carrying capacities and dimensions. New York Belting and Packing Co., Passaic, N. J.

Industrial Cable.—Catalog GEA-1838, 128 pp. Describes all standard types of insulated wires and cables used for industrial application in transmission, distribution, and control, as well as for use on or with electric equipment such as mining machinery, locomotives, arc welders, and Neon signs. Another publication, Bulletin GEA-1837, on "How to Select Insulated Cable," should prove valuable to all users of cable for general reference purposes. General Electric Co., Schenectady, N. Y.

Diesel Engines.—Catalog, 20 pp. Describes stationary-type Diesel engines of the 4-cycle, single-acting, solid-injection type, with box-type housing, cylinder liners, and overhead chain-driven camshafts, fully enclosed and provided with automatic lubrication throughout. The I-R Diesel engine is built in sizes ranging from 175 to 1,500 bph and is applicable for direct-connected a-c generator drive, gearing to pumps, direct connection to compressors, for belting to line shafting, and for similar work. Ingersoll-Rand Co., 11 Broadway, New York.

Motor Maintenance.—Booklet, 64 pp. "The Brush Phase of Motor Maintenance"; a non-mathematical explanation of the causes and cure of brush, commutator and slip-ring troubles on rotating machinery. Diagrams and data on commutation, current collection, armature and field reaction due to load are included. Brush, slip-ring, and commutator maintenance methods; the characteristics and manufacture of carbon brushes; and a brief discussion on contact drop, vacuum effect, and other brush properties are dealt with. Ohio Carbon Co., 12508 Berea Road, Lakewood, O.

Phase-Checker.—Bulletin 165, 4 pp. A balanced statiscope for use between two lines to determine the phase relationship between them. It is employed to check phases on lines at the disconnect switches in the substation; consists of a Neon tube and condensers enclosed in a hard rubber case provided with a rubber handle; light in weight, easy to operate, and positive in its indication. The instrument is extremely simple to operate, and no preliminary set-up is necessary. There are no metal parts exposed, insuring safety in operation. Made in 2 sizes—2,000 to 7,500 volts and 7,500 to 15,000 volts. Minerallac Electric Co., 25 N. Peoria St., Chicago, Ill.